NOTES ON CONCRETE AND WORKS IN CONCRETE

JOHN NEWMAN

NOTES

ON

CONCRETE

AND

WORKS IN CONCRETE.

NOTES

ON

CONCRETE

AND

WORKS IN CONCRETE.

ESPECIALLY WRITTEN
TO ASSIST THOSE ENGAGED UPON PUBLIC WORKS.

BY JOHN NEWMAN,
ASSOC. M. INST. C.E., F.I. INST.
AUTHOR OF 'EARTHWORK SLIPS AND SUBSIDENCES,' 'NOTES ON CYLINDER BRIDGE PIERS, AND THE WELL SYSTEM OF FOUNDATIONS,' SCAMPING TRICKS AND ODD KNOWLEDGE OCCASIONALLY PRACTISED UPON PUBLIC WORKS,' ETC. ETC. ETC.

SECOND EDITION. REVISED AND ENLARGED.

London:
E. & F. N. SPON, 125 STRAND.
New York:
SPON & CHAMBERLAIN, 12 CORTLANDT STREET.
1894

PREFACE

TO

THE SECOND EDITION.

THE first edition of 'Notes on Concrete and Works in Concrete' having become exhausted, and a second edition demanded, the Author has almost entirely re-written the book, adding much fresh information.

It is not intended to be an exhaustive treatise on Portland cement concrete, but in some respects a kind of miniature encyclopædia on the subject, written with the object of assisting those who have to use the material in works they design, specify, or erect, and also to supply the practical information generally required, and not to be obtained in so succinct a form; and it may be said to be written by an engineer for engineers and all users of concrete.

The Author feels privileged in offering his acknow-

ledgments to the authorities he has mentioned, and also to the Profession and the Press, here, in India, the Colonies, the United States of America, and on the Continent, for their favourable reception of the first edition of the book.

J. N.

London, 1893.

CONTENTS.

CHAPTER I.

CHAPTER II.

FINENESS AND WEIGHT OF PORTLAND CEMENT.

CHAPTER III.

AIR-SLAKING, STORING, AND SHIPPING, EXPANSION AND CONTRACTION.

CHAPTER IV.

TESTING PORTLAND CEMENT.

CHAPTER V.

THE SETTING OF PORTLAND CEMENTS.

CHAPTER VI.

SAND, GRAVEL, AND STONE.

CHAPTER VII.

PROPORTIONS OF THE INGREDIENTS.

CHAPTER VIII.

MIXING CONCRETE.

CHAPTER IX.

DEPOSITING CONCRETE IN WORK.

CHAPTER X.

TABLES OF STRENGTHS.

CHAPTER XI.

FACING CONCRETE. CEMENT GROUT.

CHAPTER XII.

CONCRETE ARCHES.

CHAPTER XIII.

CEMENT AND LIME MORTARS.

CHAPTER XIV.

CHAPTER XV.

THE DEPOSITING IN SITÛ SYSTEM.

CHAPTER XVI.

LOWERING THROUGH WATER FRESHLY MIXED OR PLASTIC CONCRETE, AND CONCRETE BLOCKS.

CHAPTER XVII.

THE BLOCK SYSTEM OF CONSTRUCTING PIER AND HARBOUR WORKS, ETC.

CHAPTER XVIII.

THE BAG SYSTEM.

NOTES ON CONCRETE,

AND

WORKS IN CONCRETE.

CHAPTER I.

GENERAL PROPERTIES; IMPURE AND FANCY CEMENTS.

PORTLAND cement concrete has become one of the most important materials in construction, and can be used with absolute confidence that the work will be of great hardness and strength, and will not deteriorate, provided the necessary care is taken in the manufacture, storing, proportions, mixing, and deposition, which long and varied experience has proved to be indispensably requisite. By its judicious application many works can now be erected, more especially submerged or partly submerged structures, that by reason of their great cost could not be constructed; for Portland cement concrete walls of average thickness for engineering purposes can be built for about one-half or one-third of the expense of masonry or brickwork.

The importance of national harbours of refuge on

the North-east coast, near the mouth of the Bristol Channel, &c., or in lieu thereof, a number of smaller refuge harbours, has been repeatedly urged for the last half-century; but the chief cause of their non-erection has been the great cost of construction; and, for a similar reason, some of the shelter harbour works imperatively required for the protection of the numerous fishing fleets on our coasts, have not been established. Doubtless, the cost of construction of a pier, or breakwater, in masonry or stone, could not be justified, except from motives of philanthropy; but, happily, by the employment of Portland cement concrete these works can now be made for one-half or one-third of their cost in masonry or stone, and in much less time; therefore, so far as regards the simple question of expense, distinct from that of utility, during the last few years, the circumstances have altered, and may possibly justify the erection of such piers and shelter harbours, which, if they had been in existence, would have saved many lives and much property.

No particular reference is herein made to the manufacture, composition, or scientific testing of Portland cement, its use as concrete being principally considered; however, it is necessary to refer to a few features connected with its manufacture, composition, and properties.

Briefly, the valuableness of Portland cement is its power of firmly uniting other substances, its cohesiveness, durability, and adaptability to be moulded into any form with a rapidity of execution unattainable with brickwork or masonry.

Apart from the cement, the nature of the other ingredients is of great importance, the mode of mixing and depositing, &c., for the practical value of the cement may be entirely destroyed without due attention to these details.

There are many matters connected with Portland cement that have caused decided opinions to be expressed, which may or may not be considered as founded upon facts or logically deduced. In the following chapters the endeavour has been made—and it is not an easy undertaking—to present the results of experience and reliable experiments without bias, and in such a way as to be useful to the engineer, architect, or any user of Portland cement concrete.

Portland cement is a chemical product, and great care and experience are required to successfully manufacture it, in order, at a reasonable cost, to produce a material that will satisfactorily sustain any tests in the laboratory, and also the strains and deteriorating influences it will have to resist in engineering and building structures under the most varied conditions. The proper selection, proportioning, mixing, and burning of the raw materials, the elimination of undissolved particles of chalk which may remain uncombined and become free lime in the cement, equable and perfect calcination, sorting and grinding, are some governing conditions in the production of a reliable Portland cement; for unless perfect combination is attained, the Portland cement cannot be considered as approaching a state of faultlessness; and it has been said that the properties of a cement depend less on the simple ele-

ments of which it is composed than upon the manner in which those elements are grouped in chemical compounds. It may be said no two makers manufacture a precisely similarly constituted Portland cement.

It is within the province of a user to specify that some ingredients shall not exceed certain proportions, but to endeavour to establish or to stipulate the exact proportions is neither politic, nor likely to be advantageous; but an inspection of the general method of manufacture by an expert may be advisable, without interfering with the function of a manufacturer or the right to reject any defective cement discovered on testing or otherwise, for Portland cement may differ greatly in quality, unless the proportions of the ingredients and general manufacture are uniform. A complete chemical analysis is also required in order to know that a Portland cement has a harmless and durable composition. Dr. Michaëlis, one of the highest authorities on the chemistry of Portland cement, has written that many of the Portland cements in use at present are very unsuitable for marine work, because of their high proportion of alumina and ferric oxide, and the proportionately low percentage of silica. The aluminate and ferrate of lime are easily acted on and softened by water, while silicate of lime remains hard, even when considerable quantities of lime have been removed from it. The two former compounds of lime form double salts with sulphate of lime, that containing alumina crystallising with considerable addition of water and increase of volume. A solution of gypsum destroys even the best Portland cement. The action of

sulphuric acid in hardened cement gives rise to the formation and crystallisation of sulphates, which may jeopardise the strength already attained.

It is generally admitted that an excess of lime is dangerous to the durability of Portland cement and its safe use in structures, but the point when it is in excess cannot be exactly determined; however, the usual proportions vary between, say, 55 and 63 per cent., and are nearer the latter percentage than the former. But a Portland cement with a small percentage of lime, mixed with an insufficient quantity of water and improperly incorporated, may be even more deleterious than a Portland cement with an excess of lime and yet thoroughly slaked before setting. Still, there is a certain percentage of lime which will combine, and any less probably reduces the strength, and any greater is injurious, and may be dangerous, as it would be in a free state, and might slowly absorb water and expand in the work at any time after the concrete was deposited. 55 per cent. is considered a sufficiently high-limed cement by some; on the other hand, many consider about 60 per cent. the better proportion, if the Portland cement has as much water as it can absorb, and is properly and thoroughly mixed. In fact, any excess of lime from underburnt nodules or otherwise, the effect of lime being to retard the setting, may be almost neutralised by thorough slaking by water, and partly by air-slaking; however, it is considered that if a cement during manufacture is properly mixed and burned, there will then be no free lime, as the lime is in partial chemical combination with the silica and alumina. The hydraulic

properties of a cement are due to silica and alumina with iron, and the latter accelerate the setting, and a minimum is therefore necessary. Some 12,000 briquettes were tested at some laboratories established under the direction of the French Minister of Public Works in 1884, and resulted in a specification being drafted, in which it is stated that the ratio of the silica and alumina combined to the lime should not be less than 0·44, and if less the cements are to be regarded as of doubtful quality, as also those containing more than 4 per cent. of ferric oxide; they must also not have more than 1 per cent. of sulphuric acid, or sulphides in determinable proportion.

An excess of magnesia is decidedly injurious, and in England more than 1 per cent. is considered deleterious, and more than 3 to 4 per cent. in Germany; but, as Portland cement can without inconvenience or increase of price have as little as 0·60 per cent. of magnesia, and generally has between 0·60 and 0·90, there is no occasion to have any excess, and as little magnesia as possible is advisable in concrete for sea works. Sulphuric acid is also deleterious when in excess, and should not exceed about 0·90 per cent., and frequently it varies from 0·40 to 0·90 per cent.

Good well-burned Portland cement is of a dull bluish-grey colour, feels silky and not gritty; if it should be coarse and gritty in the hand it denotes that it is insufficiently ground. The grey cements usually have the smaller residue. The colour and composition should be uniform, and not change with age. If the colour is a light buff shade, it usually indicates the

presence of too much clay. Portland cements of a light colour are usually the quicker setting.

Some German microscopic experiments on good and bad Portland cements showed that the particles in good Portland cement were angular fragments, like small scales or thin splinters, and those of bad cement resembled small nodules or rounded grains like sand, and this was found to be the unvarying rule after large numbers of specimens had been tested.

The proportions of chalk and clay adopted in the best manufacture of Portland cement vary slightly in each locality, according to the different geological conditions, so that no one analysis is an absolute guide. The better plan is to specify the tests a cement is required to stand, and leave the analysis of the ingredients to the manufacturer (unless it is some fundamental essential, such as that the cement shall not contain above 1 per cent. of magnesia and no carbonate of lime, as recommended by Mr. Harrison Hayter), as he cannot fail to have the greater knowledge of the process of manufacture of Portland cement; but a detailed analysis of its composition should be required with each delivery in any important work.

There is one point, however, which should be specified, namely, that no "foreign" ingredients be allowed to be mixed with the true Portland cement as generally composed and accepted, i. e. that no adulteration of the cement be permitted.

Extreme caution should be observed in receiving statements as to the good effects of adding any "foreign" substances to pure Portland cement. No

newly composed cement should be used until its superiority is established by elaborate tests as to its adhesiveness, tensile, torsional, and compressive powers, and the absence of any tendency to "fly" or crack; and its durability must be proved, as the addition of a "foreign" ingredient may apparently increase one of its powers and decrease all or some of the others, and render the cement dangerous. In fact its behaviour may no longer be that of true Portland cement, and for all practical purposes it should be considered a new or different material.

The dissimilarity in chemical composition alone makes it necessary to regard Portland and fancy cements differently, and here particularly the analytical chemist is of the utmost assistance, and mere short period mechanical tests, however favourable, should not be solely relied upon, for they may not indicate a durable cement, as perhaps in air a fancy cement may be useful, but when such a substance is submerged, or alternately wet and dry, and concrete made with such cement is placed in sea water, it may become speedily disintegrated.

What is called magnesian cement has been tried in France, but failed to succeed, as such cement swells in water or moisture, owing to the large quantity of magnesia in the rock from which it is manufactured. In the cement referred to, 16 to 28 per cent. of magnesia was present, being at the least some twenty to thirty-five times more than that in good English Portland cement.

Experiments during a period of six months, made in

1883 by German experts for the German Association of Cement Makers, showed that if "foreign" ingredients, such as silicates of lime, powdered blast-furnace slag, limestone, brick powder, lime, and fine sand, mixtures of slaked lime and sand, ground clay shale, plaster of Paris (if more than 2 per cent.), trass, and ultramarine were added, the strength of the Portland cement was impaired. On the other hand, Professor Tetmajer, of Zurich, states from his experiments that when Portland cement was mixed with sand, or finely ground ingredients containing silicic acid *in a state adapted for chemical combination*, adding certain ingredients, pure blast-furnace slag, composite slag, and mixtures specially rich in active silicic acid, the strength was increased and maintained.

Tests have shown that the compressive strength of Portland cement concrete is much reduced by additions of sugar or soda, and that Portland cement adulterated with sugar contracts considerably. Fancy cements cannot be considered nearly equal or as reliable as Portland cement, and it is well to only regard them as more or less interesting experiments, until they are thoroughly proved to be trustworthy by many years' trial.

With regard to slag cements, Mr. Redgrave has stated it has been definitely ascertained that no slag contains in itself a sufficient amount of lime to produce a cementitious action. Samples of slag, which appear by analysis to give very similar results, differ widely in their behaviour when made into cement.

In some French experiments with dolomitic cements, burnt at a high temperature, the free magnesia in them

was at first quite inert, but it at length became hydrated, and consequently increased in volume, and as this took place long after the setting of the cement, complete destruction of apparently sound works ensued, and proceeded much more rapidly when the mortar was exposed to the action of water. Under cover, years elapsed before the same effect occurred. This shows the treacherous nature of dolomitic, or magnesian cements.

CHAPTER II.

FINENESS AND WEIGHT OF PORTLAND CEMENT.

Importance of fineness — Sieves — The residue — Weight test — Specific gravity, &c.

The importance of uniform fineness in Portland cement has been proved under every condition, and repeated experiments have shown that it cannot be ground too finely, or be too carefully sifted, its tensile strength being dependent upon its fineness when it is mixed with sand; and Mr. Mann's experiments also demonstrated that the finer the cement the greater the adhesive strength, it falling considerably as the amount of the residue increases; an analysis of the experiments showing that, approximately, the adhesive strength was not far from being inversely as the percentage of the residue upon the sieve.

One of the chief reasons which causes uniform fineness to be of such great moment is obvious, as the especial value of Portland cement is, apart from its own strength, its power of durable adhesion to other substances; therefore the object to be gained is to thoroughly and equally coat and cover any particles of gravel or sand, as perfectly as if they were surrounded by water, and the finer the cement is ground the nearer it approaches the desired condition of an impalpable powder or flour, and

the more readily it combines freely with the water used in mixing it. All coarse particles, i.e. small lumps of cement in an unground, or partially ground state, should be removed, as they do not set together and are little better than sand; although the identical lumps may set readily, and as hard as desired when finely ground, but although the coarse particles may be the most highly calcined portions, and may contain only a trace of free lime, they may not combine with water owing to the clinker having been completely fused. If there were no other reasons for the necessity of very fine grinding this alone would suffice, and it is manifest that it is better to have more coarse sand in concrete, than particles of unground, or partially ground cement; because the cement in such a state can only be regarded in practice as sand, although by nature, cement, and therefore, all residue upon a sieve after sifting increases the ratio of the aggregates, and reduces the effective proportion of the cement. The risk of free lime in the cement is also reduced by fine grinding.

In order to obtain a state of repose in Portland cement when mixed with water *uniformity* in the fineness is necessary, because the coarser particles cannot absorb the same quantity of water in the same time and manner as the finer particles, and they are always ready to take up any deficiency of water. To have Portland cement that is *equally* finely ground is therefore to be desired, as then chemical combination is much more complete, for experiments have shown that the coarse grains are inert during the earlier period of setting, although they eventually may undergo a chemical change, but it is

almost confined to the surface. The aim should be to reduce *all* the properly burned particles to a state of flour, so that chemical action on mixing with water may be simultaneous and equable.

Mr. Grant, in some experiments with Portland cement weighing 113 lbs. per bushel, found that when unsifted it had a tensile strength of 375 lbs. per square inch, but when sifted, the same cement weighing only $110\frac{1}{2}$ lbs. per bushel, increased in strength, the highest test being 427 lbs. per square inch; and he considered that although a higher price for the very fine cement was required, it was ultimately the most economical, even to the extent of adding to the cost of the cement in proportion to the less residue.

In many experiments at Portsmouth dockyard extension works, it was found that the average weight per bushel of the cement after screening was 106 lbs., against 115 lbs. before screening, and as delivered on the works.

Some experiments with $2\frac{1}{4}$ square inches briquettes, to ascertain the tensile strength at one month old, made by Mr. Colson, with Portland cement as delivered, as first screened through a sieve $34 \times 34 = 1156$ meshes to the square inch, then the latter screened through a $58 \times 58 = 3364$ meshes per square inch, and finally a $65 \times 65 = 4225$ meshes per square inch, briefly summarised, show that the *neat* Portland cement was reduced in strength from 12 to 18 per cent., but when mixed with sand in the proportion of 1 of sand to 1 of Portland cement, the first screening increased the original strength of the cement as delivered 10 per cent., the second 17 per cent., and the third, 23 per cent. In the case of a

two of sand to one of Portland cement mixture, the increase of strength was at the first screening 14 per cent., second screening 28 per cent., and the third screening 40 per cent. The average residue of all the Portland cement delivered on the Portsmouth dockyard extension works was about 11 per cent. when screened through a sieve having 1156 meshes per square inch.

These and various other experiments demonstrate the value of screening, and therefore fineness, whenever Portland cement is mixed with sand, and further corroborate others which have shown that tests of cement with sand should never be omitted, as tests with neat Portland cement may produce opposite results to tests of Portland cement mixed with sand, in which condition Portland cement is generally used. The relative weight of this Portland cement was, as delivered, 112·15 lbs. per bushel, or 87·61 lbs. per cubic foot; at first screening, meshes as before in each case, 104·85 lbs. per bushel, or 81·91 lbs. per cubic foot; at the second screening, 98·30 lbs. per bushel, or 76·79 lbs. per cubic foot; at the third screening, 94·75 lbs. per bushel, or 74·02 lbs. per cubic foot; and the ratios were 1, 0·934, 0·876, and 0·844.

From some experiments made by M. Feret to determine the size of grains beyond which Portland cement must be considered inert, it appears that the substitution of sand for the coarse grains of cement retained by a sieve of 5800 meshes per square inch did not appreciably modify the strength—in fact, the breaking strains were rather higher when the sand took the place of the cement.

With regard to sieves, they are seldom quite regular or similar, and with the same sieve the amount that will pass through it depends upon the violence and duration of the sifting. By continued shaking, larger grains can be made to pass and some particles will continue to do so. The gauge of the wire should be mentioned, as a very fine wire might be used, which would increase the size of the holes, and with the same number of meshes the area of the openings can readily be doubled, and it should not be overlooked that if the size of the wire is not specified, the number of meshes per lineal inch does not determine the size of the openings in a sieve. A usual size for sieves is 0·0086 inch, or No. 32 B.W.G., for No. 60 mesh of 3600 meshes per square inch; or a No. 30 B.W.G. for 0·012 inch; 0·007 inch wire, or No. 34 B.W.G., for No. 120 mesh, or 14,400 meshes per square inch. A comparison of the different sizes in decimals of an inch of B.W.G. will at once show the variation that can be made in the fineness of the meshes, quite irrespective of their number.

Respecting the number of meshes per square inch, and the amount of residue left upon the sieve after sifting, considerable diversity of opinion exists. The highest number is the German of 32,000 meshes per square inch, or 179 per lineal inch, the lowest having about 1600 meshes per square inch, or 40 meshes per lineal inch, the maximum residue being the same in each case. In Germany, sifting is sometimes done by means of two or three sieves of different degrees of fineness, of course commencing with the sieve having the least number of meshes per square inch.

In England, Portland cement ground as finely as in Germany is not freely offered. In England, 5800 meshes per square inch, or 76 meshes per lineal inch, is now frequently specified, and a maximum residue, after sifting, of 15 or 10 per centum by weight. 10 per cent. residue on a sieve having 2500 meshes per square inch is often named, but it is better to pay a higher price and obtain cement more finely ground, and a finer sieve test is here recommended. As the fineness is increased, the weight per bushel will become lighter, and the specified weight must be correspondingly reduced.

It is obvious that exceedingly fine grinding increases the cost of the production of Portland cement; but it is undoubtedly better to increase the ratio of the aggregates to the cement, within reasonable limits, to balance the increase in cost, than have imperfectly ground Portland cement with a large residue after sifting, which residue is worthless in its unground state as a cementitious agent, although probably the better portion of the cement when finely ground, if not completely fused in the manufacture, as it is generally the best calcined. Hence it is obvious that rather than increase the number of meshes per square inch, and allow more residue, it is preferable to be satisfied with an average fine sieve, say of 5800 to 10,000 meshes per square inch, and allow a very small residue, say 10 per centum, as a maximum; thus ensuring that the hard or well-burned particles of the cement are finely ground, as they are not so easily ground as the softer particles, and, therefore, are the most likely to be the residue.

Fine grinding of *all* the mass is the object to be desired, and not merely fine sifting with a large residue on the sieve. Some specifications err rather on the side of not requiring sufficiently finely ground cement, and allow too much residue.

A coarsely ground cement may be considered as one that will leave about 20 per cent. residue on a sieve having $50 \times 50 = 2500$ meshes per square inch. A finely ground one that would leave 5 per cent. residue on a sieve having $75 \times 75 = 5625$ meshes per square inch. A Portland cement leaving a $7\frac{1}{2}$ per cent. residue on a 2500 meshes per square inch sieve can be obtained at the ordinary price, and perhaps only a 10 per cent. residue on a sieve of 5800 meshes per square inch. Some specifications have only required a 10 per cent. residue on a sieve of 2100 meshes per square inch, but this is hardly a desirable degree of fineness, and a sieve of 5000 meshes with the same residue is to be preferred. A Portland cement leaving only $\frac{1}{2}$ per cent. residue on a sieve of 2500 meshes per square inch can be obtained at the ordinary price; in proof of which, reference is made to some tests of Portland cement manufactured by the Reliance Portland Cement Co., Strood, Kent, made by the Board of City Works, Halifax, N.S. The fineness was $\frac{1}{2}$ per cent. residue on a sieve of 2500 meshes per square inch. The tensile strength at 7 days was 500 lbs. per square inch of section; at 14 days, 550 lbs. M. Candlot has given the following degrees of fineness as desirable:—3 sieves, having 2090, 5806, and 32,257 meshes per square inch. A Portland cement may be accepted which gives a

residue of 1 per cent., 5 to 6 per cent., 30 to 35 per cent. on the respective sieves, and a well-manufactured Portland cement should not leave more than no residue, 1 to 2 per cent., and 24 to 28 per cent. on the respective sieves.

Baron Quinette, Engineer-in-chief of the Port of Havre, found, in the case of a Portland cement specified to have not more than 10 per cent. residue on a sieve of 2100 meshes per square inch, that the residue by itself was almost inert, and the mortar formed with it, which only set after a long time, had a tensile strength of only 13 lbs. per square inch at 4 months, 43 lbs. at 9 months, and 76 lbs. at 18 months.

To show the value of fine grinding, and also that very finely ground Portland cement can be obtained, Mr. Watson has mentioned that he had manufactured Portland cement to a fineness leaving 8 per cent. residue on a 5800 sieve, 19 per cent. on a 10,000, and 31 per cent. on a 30,000 sieve; the weight being 112½ lbs., and the tensile strength 350 at 7 days, and 480 to 500 lbs. at 28 days. A 12 months' trial showed, with a fineness of 10 per cent. residue on a sieve of 5800 meshes, that the strength was exactly 100 lbs. per square inch higher than with 10 per cent. residue on a 2500 meshes sieve, and in the standard sand briquettes, i.e. 3 to 1, the increase of strength was 50 per cent.

Some standard size of B.W.G. for the meshes may be drafted by some competent authorities in council, but at present it is difficult, and in many cases impossible, to obtain the actual size of the wires used in tests; therefore, a mere comparison of the number of the

meshes cannot be regarded as absolutely trustworthy, as wire of any size may be used. However, the sizes generally vary from No. 30 B.W.G. = 0·012 inch, for comparatively coarse sieves, to No. 36 B.W.G. = 0·004 inch, for a fine sieve. The German standard rules require the thickness of the wire to be 50 per cent. of the width of the mesh. A recommendation for the adoption of standard sizes by a competent tribunal would be of value alike to the engineer and manufacturer, for although the fineness and percentage of residue are almost universally regarded as matters of much importance, the size of the mesh wire has been but slightly considered; nevertheless, as has been stated, it can be so arranged as to afford, with the same number of meshes, a variation of fully 100 per cent. in the area of the openings.

The rules published by the Prussian Minister of Public Works in 1887, state that on a 5806 mesh sieve per square inch, the wire having a thickness of one-half the width of the mesh, the cement must not have more than 10 per cent. residue.

In a specification for French Government Harbour works, neither the degree of fineness nor the sizes of the mesh are mentioned, but, in the determination of the weight of the cement, only the fine powder is used which has passed through a sieve of 32,257 meshes per square inch.

The Committee of the American Society of Civil Engineers' recommendation as to the fineness of Portland cement was, first sieve, 2500 meshes per square inch; second sieve, 5476 meshes per square inch; third sieve, 10,000 meshes per square inch.

The crucial point is to determine the degree of fineness that is necessary for Portland cement to make good, durable concrete, as there is one when the cost of a finer ground cement is not justified by a corresponding increase of quality; but consideration of the importance, or the degree of exposure and trial to which it will be subject, must to some extent govern a correct decision. Probably, the minimum safe degree of fineness and maximum residue is about a 7½ per cent. residue on a sieve having 2500 meshes to a square inch, and a 10 per cent. on one having 5000 meshes to the square inch.

Apart from any increased strength to resist strain, the value of fineness in cement is to make a concrete as compact and impervious as possible, a matter of especial importance in marine works, because the finer the cement the more thorough incorporation, denseness, less liability to crack and fissure, and the more perfect hydration. In the case of cement that will pass through such a fine sieve as 32,000 meshes per square inch, and leave no residue, and also if there is any residue it be *not* used, Dr. Michaëlis has stated that from experiments and research, a mixture of a cement of but moderate fineness with 2 or 3 parts of sand would, after some time, possess no greater strength than the very finely ground cement mentioned mixed with from 5 to 6 parts of sand.

It is generally admitted that the residue has hardly any cementitious value, and that sand is nearly or is of as much use. This is further referred to in Chapter VII., "Proportions of the Ingredients," and it is a

matter for consideration whether it is better or not to have a Portland cement leaving no residue, or only a very small one, say, 1 to 5 per cent. on a sieve of reasonably moderate fineness, than to have, say, 15 per cent. residue on a very fine sieve. Uniformity, combined with fineness, is to be desired, for, if the size of the particles vary, hydration and setting cannot be simultaneous or equable.

With regard to the important and controverted question of the weight of cement, and its influence on the strength of cement, it is possible to specify so heavy a weight as to demand coarse grinding, for the cement that is the more finely ground will be the lighter per given measure, as the heavier weight of the residue remaining on a sieve shows; but it is to be observed that with similarly finely ground cements the heavier would in all probability be the better, because it would be obtained from the more thoroughly calcined material which, however, is the harder to grind. As a rule, the heaviest cement is the coarsest. Heavy cement has been ascertained to contain 30 per cent. of grains exceeding $\frac{1}{50}$th of an inch in diameter, and such particles have been found by experiment, when mixed neat, to be incoherent and not to set.

A simple weight test may be said to be deceptive, as in great measure, very heavy cements, which are the most highly burned, and may be said to be those heavier than about 113 or 114 lbs. per bushel, are not well or sufficiently ground. A weight test alone, without a specific degree of fineness, is, therefore, no indication of strength, but may be precisely the reverse. In

all cases, the Portland cement is supposed to be well burnt, as that affects the strength; for instance, well burnt Portland cement, somewhat coarsely ground, experiments have shown to be stronger than soft clayey cement finely ground, both mixed neat.

In weighing cement care should be taken in filling the measure, because the weight can be increased as much as 10 per cent. by filling a measure from a considerable height, or with force ; and the larger the size of the measure the greater the density. To ascertain the true weight of cement it should be gently run in from a hopper, the bottom of which, and the lower end of the shoot being at an elevation above the measure not exceeding one foot six inches, and six inches respectively, and the inclination of the shoot should not be steeper than is necessary for the cement to run leisurely : a slope of $1\frac{1}{2}$ to 1 to $1\frac{3}{4}$ to 1 usually effecting this. The weighing should take place immediately upon the material being received from the manufacturer.

It is well to adopt a standard measure and weight per bushel to ensure uniformity of cargoes and deliveries, and in comparing weights the measures must be of the same size. As the effects of a long voyage or transit from the works is to reduce the weight considerably, the weight at the works cannot be taken as that on delivery in such cases, for about 10 per cent. is an ordinary reduction in weight, and by thinly spreading on a floor for a week or so, the weight may be similarly reduced.

The correct relation of weight to fineness and

strength is of importance, because, if too heavy a cement is specified, in order to obtain the weight, it may be necessary to have coarse particles in the cement. These, in their unground state, although cement, for purposes of concrete must be regarded as sand, and somewhat dangerous sand, as they may "fly." It is, therefore, obvious that to specify too heavy a cement is to invite a manufacturer to deliver residue, and also to pay the price of cement for a material only equal to sand. A cement leaving a residue of, say 20 per centum after sifting, and which residue is used in the work, is not neat cement in strength, but four of cement to one of sand. In fact, to specify for an exceptionally heavy weight per measure, with the idea to gain strength, is to defeat the very object desired, and is to pay for useless weight. It is better and cheaper to pay more for a very finely ground cement than to buy coarse material at a reduced price, as the weight taken alone does not prove the quality, for a cement may be of equal or heavier weight than another more finely ground or screened, and may have a less tensile strength when it is mixed neat, but it is the better cement when mixed with sand or used in work.

In a few recent specifications no weight per bushel is specified, but the specific gravity, degree of fineness, and quantity of residue are particularised, together with the time of setting tests and the breaking strain, &c. Thus a manufacturer can supply cement of any weight per bushel subject to the condition that it has the required degree of specific gravity, fineness, and strength, and does not yield more than the maximum

residue allowed; the buyer being considered secure, as the finer the cement, provided its manufacture is identical, the lighter it is; and therefore, the fineness required prevents an abnormally heavy cement being delivered, and an exceptionally light one is guarded against in the interests of the makers, if payment is made by weight. Perhaps, taking a general view, the better plan may be, as is sometimes done, to specify a fixed range within which scale the weight of the cement must be contained; however, the specific gravity should, if possible, always be ascertained.

The heaviest weight is about 130 lbs. per striked imperial bushel, or $101\frac{3}{4}$ lbs. per cubic foot, but this is far too heavy to be of a reliable nature, and such Portland cements are now seldom manufactured. To fix a correct limiting heaviness, or lightness, is a most difficult matter; but with the present knowledge of the material, and to exclude lightly burnt cement, although finely ground, there is no particular advantage in a cement, on delivery, weighing heavier than about 118 lbs., nor lighter than 108 lbs. per striked imperial bushel; and the most usual weights are from 110 to 114 lbs. per bushel, as then a finely ground Portland cement may be secured; all weights taken before sifting. In Germany, where fine grinding prevails more than in England, Portland cement weighing about 70 lbs. per cubic foot, or, say 90 lbs. per bushel, is not uncommon.

In the last few years the weight per bushel test has not been regarded with favour, and may be considered as becoming superseded in most cases by a specific

gravity test, principally because of the ease with which any measure may be made to contain, without apparent effort, more or less cement. A weight per bushel test is that of the cement with air spaces in it, whereas a specific gravity test gives the actual weight of the cement only, and therefore is not dependent upon the extent of the interstices of the particles which are occupied by air. Briefly, by knowing the specific gravity of different kinds of Portland cement, their relative weight can be reliably ascertained without any of the contingent qualifying circumstances that accompany a weight per bushel test. In order to show the influence of the air spaces in weighing, the difference between a specific gravity and a weight per bushel test is very considerable, and may be not far short of 100 per cent., but the proportion will vary, for if the weight per bushel is determined by weighing cement deposited in a measure of large size, owing to the greater compression, the particles will form a denser mass than those in a smaller one. An objection to the specific gravity test has been raised because all the products of the kiln, whether pure clinker or not, except any insufficiently burnt lumps of a buff colour, have nearly the same specific gravity, and also that a coarsely or finely ground cement will have the same specific gravity; on the other hand, it has been declared it gives a fairly reliable test that the Portland cement has been well burnt.

The best specific gravity cannot be unalterably established, but in properly composed, burnt, and ground Portland cements it will generally vary from 3·07 to

as high as 3·15, the most usual figure being 3·10 after one month; but the specific gravity decreases after about four weeks, and tests have shown that the same Portland cement may lose about 0·10 of its specific gravity in four months. Any Portland cement, having a specific gravity below 3·07 at one month, it perhaps is well to regard with some suspicion increasing almost as it becomes less, even when giving a high tensile strength in a few days, such as seven, and it may be expected to more or less deteriorate and be unreliable.

CHAPTER III.

AIR-SLAKING, STORING, AND SHIPPING, EXPANSION AND CONTRACTION.

Store sheds—Time required for aeration—Effect of time—Expansion and contraction.

THE object of air-slaking Portland cement is to endeavour to purge it of any lime in a free or uncombined state, which expands, and if deposited in the work is a fruitful source to cause a concrete to "blow" or crack. In coarse Portland cements, i.e. those not finely ground, it is more required than in the case of finer cements; consequently, it may be said that a Portland cement may be so finely ground and well manufactured that no aeration would be necessary, if it could be declared that it is certain there is no free lime or under-burned nodules in the Portland cement. Briefly, it is adopted as a safeguard against what are called over-limed Portland cements, or those having particles of free lime in them, and it is generally agreed that in many cases it is the simplest, if not the best practical way of making a Portland cement fit for immediate use after delivery. By aeration any free lime is carbonated, or rendered inert, and, at present, there is no evidence to show that sound Portland cement (and none other should be used) is deleteriously affected by the action of carbonic acid, but, on

the other hand, many of the highest authorities on the chemistry of the subject declare it increases the durability and reliability of a Portland cement, and also the tensile strength, provided it is not overdone, and in any work of importance freshly ground Portland cement should not be used without being properly air-slaked, and any in a hot state should not be made into concrete, for thorough cooling is necessary, and in receiving Portland cement after a long voyage, it should be examined to ascertain if it is cool, as instances have occurred in which after being shipped many thousands of miles, the cement was hot.

Portland cement is generally believed to improve by being kept, if properly stored in a dry place and protected from dampness and draughts; but, as chemical changes take place during storing, it has been stated by Dr. Erdmenger that some Portland cements become slow setting, while others set more rapidly in consequence of being stored.

As a rule, it is advisable to store Portland cement in timber sheds, with a wooden or concrete floor, raised one foot or so above the level of the ground, unless a brick or stone building has been constructed for that purpose; for, if it be deposited to any considerable depth, it will probably crack and bulge, or rend a brick or stone structure, the increase in bulk of Portland cement after grinding being about 5 per cent., without an increase in weight. Almost all Portland cements increase in bulk after grinding and delivery from the manufacturers, and by being spread in very thin layers the weight may be reduced about 10 per cent. in a week or so.

It should be spread in a shed for several days before being mixed, and be stored and turned over in layers for not less than three weeks or a month before being used in the work, but a longer time than about three months it has not been shown is required, but time is essential to effect the air-slaking of the free lime in the cement, which can generally be ascertained after twenty-one days have elapsed by the 5 per cent. or so increase in bulk. This expansion will either take place in the store shed, or in the work if the cement has not been air-slaked. It has been proved by some experiments, that after one year's storing in a dry place, or even in barrels, there is no deterioration in Portland cement, provided it is kept from moisture and draughts; but this is not always the case, for other experiments have shown a loss in the tensile strength in six months of 20 per cent., and it seemed as if the decrease would continue. On the whole, it would appear that Portland cement should be used not later than six months after delivery, but much depends upon the storing being properly effected.

Cases may occur in which it may be necessary to use a Portland cement of doubtful quality; in such an event the cement should be exposed to the air in thin layers so as to lessen any inequalities in the mass from the raw materials not having been sufficiently carefully chosen, mixed, burned, or ground, and plenty of water should be employed in mixing it.

Attention cannot be too strictly given to the proper air-slaking of cement, although it has generally a tendency to make the process of setting slower. Even though the cost of temporary wooden sheds, and the inconvenience

and delay from being unable to use the Portland cement immediately on delivery may be considerable, it should seldom be omitted, as the air-slaking of cement is not a mere fanciful refinement.

As the object of exposing cement to the air is to slake any lime in a free or uncombined state in the cement, and particularly when this cannot be thoroughly done or only partly so from the material having to be used very soon after delivery, the best thing to do appears to be to employ plenty of water in mixing it, so as to endeavour to slake every particle, and then any deficiency in air-slaking may be compensated by complete hydration of any such free lime or nodules. However, until reliable experiments extending over a considerable time have been made, it cannot be said it is established that additional water-slaking is equivalent to proper and effective air-slaking, but it is a precautionary measure, and one easily employed in the absence of the other safeguard, and it seems advisable to adopt it within reasonable limits, i.e. so as to ensure the perfect hydration of every particle of a cement.

In shipping Portland cement to hot climates, it should not be put into casks until it is perfectly cool; and on its being taken ashore, it should be removed, spread in layers, and turned over, in order to get thoroughly cool before being used, or its strength will be depreciated. Mr. William Parkes mentioned that the Portland cement used at the Kurrachee breakwater, which was shipped from England, swelled about 10 per cent., arising from absorption of moisture in transit, and in storage.

The effect of long voyages is a slight total increase of weight from the absorption of moisture; but when taken out of the casks cement usually swells, and becomes of about one-tenth less specific gravity than its weight when it has left the cement works. It is well to arrange with a manufacturer the weight of a cask and a sack, so as to make a standard; and in order to ensure uniformity in deliveries, and to facilitate shipping arrangements.

Where transport is difficult it is advisable to have the barrels of comparatively small size, and not exceeding $1\frac{1}{2}$ to 2 cwt. each in weight, so that they can be more easily carried and handled.

Portland cement for shipment is often delivered in 2 cwt. casks which equal 2 bushels if the cement weighs 112 lbs. per bushel. Cement to weigh 2 cwts. without the casks.

It is well to have Portland cement delivered on works in bags or casks of such size that a certain number can be regularly used in proportioning the mixture, so as to facilitate correct incorporation and prevent the contents of a bag being divided.

It has been found that the loss in transit of Portland cement in barrels shipped from England to India is such that the full quantity put in a barrel is not obtained on delivery at the end of the voyage. Waterproof sacks are occasionally used with the view to lessen any loss of cement.

Mr. Bevan has mentioned a case in which Portland cement, weighing 112 lbs. per bushel at the works in England, by the time it reached its destination (the

interior of Australia) was naturally reduced in weight to 102 lbs. per bushel, or about 9 per cent.

In an experiment to find the loss of weight due to storing it was found that a 115 lbs. per bushel cement on delivery weighed 5½ per cent. less at one month and 2 months, 8½ per cent. at 3 months, 9 per cent. after 4 months, and 10 per cent. at 5 months, and the same after 6 months and subsequently.

With respect to the expansion and contraction of Portland cement and concrete, in the chapters on "Testing Portland Cement," and "Depositing Concrete in Work," the subject is referred to, but generally the expansion of Portland cement is caused by the hydration of particles of lime in it which are in a free and uncombined state.

For practical purposes any natural expansion, or contraction, of the sand, gravel, or stone, may be disregarded; hence it is the cement and the mixing and setting operations that alone may be taken as creating any variations in the size of the mass causing cracks and fissures. It is, therefore, obvious that the greater the ratio of the quantity of sand, gravel, or stone, to cement, the less the expansion or contraction, if both masses are mixed and deposited under the same conditions; and experiments have proved this to be the case, as they have also shown that the expansion of Portland cement of good quality is very little, and is so slight that it need hardly be considered in ordinary use; but all Portland cements contract when drying and expand upon being put into water. The degree of expansion is greater in freshly manufactured cement than that taken

from a store, after having been air-slaked and deposited some considerable time; and cements with an excess of lime in them, or those lightly burnt, expand the most because they contain particles of unslaked lime. On the other hand, cements with an excess of clay in them usually contract rather than expand; the over-limed cement being the most dangerous. Both should be avoided.

Prof. Tetmajer in considering the important quality of the constancy of volume in cements, has defined hydraulic cements as those which, when mixed neat, permanently retain the form in which they were moulded in the air or under water. With respect to cements which change their volume and deteriorate under water, he considers the result may be due to three causes. (1) Excess of constituents, which increase their volume by oxidation and subsequent absorption of water; to these belong the sulphides, more especially sulphide of calcium. (2) Coarse grain, insufficient homogeneity, and defective burning. In this case the destructive agent is quicklime, surrounded by a crust of calcium ferrate. (3) Excess of substances requiring slaking, including quicklime, gypsum, and magnesia. To accelerate the tests for defects under (2) and (3) test pieces may be placed in steam or boiling water, instead of cold water as in the normal tests. However, this treatment is only suitable for Portland cement and slag cements; for other kinds it is too violent.

A report of a United States of America Government Committee on the compressive strength of Portland cements, &c. (see 'Transactions of the American

Society of Civil Engineers,' 1887), embodied the following conclusions with respect to the contraction and expansion of Portland cements, which were of American origin. Cement mortars hardened in water, i. e. submerged, increase for at least three months, and at that period the expansion was 0·04 in 0·25 per cent. in the case of neat cement, and for 1 of Portland and 1 of sand, 0·0 to 0·08 per cent., the expansion being the same in all directions, and less in mortars containing sand. Quick-setting cements expanded and contracted the most, the changes being less in water than in air. Cement mortars hardened in air diminished for at least three months, and the contraction in the case of neat cement was 0·14 to 0·32 per cent., and for a 1 of Portland cement to 1 of sand mixture, 0·08 to 0·17 per cent. These experiments give an idea of the general rate of expansion and contraction of such cements, but variations from the original bulk must be governed by the nature of the cement, aggregates, and the usual other conditions that regulate the character of the cement and mortar. It will be noticed that the rate of contraction of Portland cement is greater than that of expansion.

Some experiments of Messrs. Dyckerhoff with neat German Portland cement, and the same mixed with three parts of sand, showed the greatest expansion to be very much less than the preceding rates, but as finely ground Portland cements were used, viz. with an average residue of 8 per cent. on a sieve of 5826 meshes per square inch, some diminution may thus be explained. The expansion was so small that it

might be considered infinitesimal in work in the case of thoroughly sound and not overlimed well burned Portland cement of good quality, which had been properly air-slaked, and mixed with sufficient water to cause complete setting and hardening.

New, overlimed, and lightly burned Portland cements are liable to appreciable, and may be dangerous, expansion, particularly when mixed without sufficient water. Some other recent experiments showed that neat Portland cement hardened in air contracted 0·04 per cent. within the first month, and continued to contract very slightly for several years. Mr. Watt Sandeman, M.I.C.E., in a paper contributed to the Institution of Civil Engineers, stated that the results of some experiments made to ascertain the reduction in volume of cement and sand, by admixture with water to the consistency of mortar, were as shown on the next page.

From the experiments it appears that the cement when gauged alone contracted about 10 per cent., and sand 20 per cent.; average of the two equal 15 per cent. When mixed, they contracted about 20 per cent.; difference equals 5 per cent. Experiments were tried with cement and sand mixed in the proportions of 1 to 2, and 1 to 3, and gauged with water, and the percentage of reduction due to admixture with each other was found to vary very little, although the percentage of reduction due to admixture with water was greater in proportion to the larger volumes of sand.

The contraction of neat Portland cement on gauging will seldom be the same It is sometimes from about

Number of Experiment.	Material.	Weight of a cubic foot of the material when gauged with water to the consistency of mortar (not including the water of admixture).	Weight of the water of admixture.	Weight of a cubic foot of the dry material.	Difference between weight of material gauged with water and material dry.	Ratio and reduction in volume of material by admixture with water, in percentage of the volume of the dry material.
		lbs.	lbs.	lbs.	lbs.	per cent.
1.	Portland Cement (Rugby) ..	104	30	94	10	10·64
2.	Silicious sand, clean and small-grained, dredged from the bed of the River Weaver	96	16·5	80	16	20·00
3.	Portland Cement and sand (same as above) mixed in equal proportions	104	22	87 *	17	19·54

* Average of the preceding.

10 to 15 per cent. of the volume of the dry material. It is much the best way to make an experiment in each case, which can be easily done, to ascertain the amount of shrinkage from the dry volume to that when wet, or properly mixed, and with the aggregates; for to generalise from a few experiments may not be a true guide, as Portland cements can be so differently constituted. The general effect of adding water in measured quantities is that the cement swells at first, and then contracts upon the addition of more water; the resulting mass has been called the minimum yield.

It may be well just to mention that the minimum yield has been estimated from some French experiments as being, in the case of hydraulic mortars, between 0·50 to 1·10, which is a wide range of bulk as compared with that of the dry substances, and is referred to simply to show the variableness of the bulk.

Taking a given quantity of raw materials, i. e. river ballast, shingle, or gravel, and sharp sand, and Portland cement, the resulting quantity of concrete usually represents a contraction in their volume of about 20 to 25 per cent., but it will vary according to the nature and the proportions of the aggregates. A shrinkage of 30 to 33 per cent. may be considered as about the maximum, and occurs with broken rock, crushed stone, and with aggregates of a softer nature.

At the Manora Breakwater, Kurrachee, the composition of each cubic yard in a concrete block was—Portland cement, 2·75 cubic feet; sand, gravelly, from river bed, 11·25 cubic feet; shingle, from Manora conglomerate quarry, 15·75 cubic feet; quarry lumps from the same, 14 lbs. to 28 lbs. each, 9·00 cubic feet; total, 38·75 cubic feet of dry materials made 27 cubic feet of concrete in place on work, the contraction being about 30 per cent. At Madras Harbour Works, the proportions used were 10·28 cubic feet of stone, 4·16 of sand, 1·66 of Portland cement; total, 16·10 cubic feet, which made 11·05 cubic feet of concrete, or a reduction of about 31 per cent.

At Emu Breakwater, Tasmania, Mr. Reid Bell found the interstices of broken basalt, machine-crushed, 2½ inch

gauge, were 44 per cent. 31 cubic feet of dry material formed 22 cubic feet of such basalt concrete, the stones being mixed with a $2\frac{1}{2}$ of sand to 1 of Portland cement mortar; this is a reduction of about 35 per cent.

Mr. Colson has mentioned, as the result of a large number of experiments, that the interstices in hand-picked stone amounted to 50 per cent. of the gross bulk. Other experiments showed that 1 part of Portland cement to 2 of sand gave an average of 2·36 parts of mortar, or a reduction in the volume of the mortar only of about 21 per cent.

Mr. R. Pickwell has mentioned that in a concrete graving dock at Newport, Mon., the materials when mixed dry were $22\frac{1}{2}$ cubic feet of broken steel slag, used because there was difficulty in obtaining stone or gravel, $7\frac{1}{2}$ cubic feet of sand, and 3 of Portland cement. Total, 33 cubic feet of dry materials, which made 22 cubic feet of concrete; the shrinkage being 33 per cent.

At the Ravi Bridge, Punjab Northern State Railway, the concrete blocks for protecting the piers from scour were composed of broken waste brick, 100 cubic feet; Kunkur lime, 16 cubic feet; brick dust, 13 cubic feet; sand, 13 cubic feet; total, 142 cubic feet, produced 100 cubic feet of concrete, the contraction of volume being about 30 per cent.

Mr. Sawyer, on the Portuguese West of India Railway, found, after careful trials, the following dry materials gave exactly one cubic yard of concrete:—Broken stone, laterite, which is of a varying nature

ranging from the hardest ironstone to compact clay, 0·84 of a cubic yard; sand, 0·28 of a cubic yard; gravel, small shingle, 0·14 cubic yard; Portland cement, 0·16 cubic yard; laterite lumps, 0·08 cubic yard; total, 1 50 cubic yard. This gives a contraction of exactly 33 per cent. of the dry materials. In another case, 22 cubic feet of broken stone, 10 cubic feet of sand, 4 of Portland cement; total, 36 cubic feet of dry materials, produced 24 cubic feet of concrete, or a reduction of 33 per cent.

Mr. Watt Sandeman made a series of experiments (1) to ascertain the proportion which should subsist between the mortar and the broken stone. He found that the interstices between pieces of broken sandstone, varying in size to what would pass through an 8-inch ring, are 36 per cent. of the whole volume, but, as the stones were in contact when this measurement was made, a percentage has been deducted from their volume, and added to that of the interstices, to obtain the volume of mortar which would be sufficient to separate the stones at all points, and to ensure the complete filling of the whole of the interstitial space. For ordinary concrete, this may be taken at 10 per cent. of the volume of the stone. For concrete to be placed under water, the proportion should be increased to 15 per cent. Dividing this additional mortar throughout 90 per cent. of a volume of broken stone, it would afford about $\frac{1}{8}$-inch as the minimum thickness of a mortar-joint at any point, assuming the average diameter of the stones to be $3\frac{1}{2}$ inches. The measure

of the interstices of 90 per cent. of a volume of broken stone, the proportion for one volume being 36 per cent., is 32·4 per cent., and adding the 10 per cent. allowed for the separation of the stones, gives 42·4 per cent. as the proportion which the mortar should bear to the 90 per cent. of broken stone contained in one volume of concrete. (2) To ascertain the volumes of the dry materials required for the mortar. The proportion previously ascertained is the volume of the mortar when set hard, but the dry materials of which it is composed contract considerably in volume. The experiments showed that the contractions of the dry materials when made into mortar were as follows :—

—	1 of Cement to 1 of Sand.	1 of Cement to 2 of Sand.	1 of Cement to 3 of Sand.
	Per cent.	Per cent.	Per cent.
First. By admixture with water*	15·00	16·66	17·50
Second. By admixture with each other ..	5·00	5·00	5·00
Third. By the cement in setting to hardness, from the condition of mortar †	4·00	4·00	4·00
Total ratios of contraction of the materials in percentage of their own volume	24·00	25·66	26·50
Total ratios of contraction of the materials in percentage of the volume of the mortar, when set	31·58	34·53	36·05
Total volumes of the dry materials, cement, and sand in percentage of the volume of the concrete, necessary to produce the 42·4 per cent. of mortar	55·79	57·04	57·68

* These percentages are the averages of 10 per cent. for the contraction of cement, and 20 per cent. for the contraction of sand.

† The contraction by setting of cement mortar, when made of different proportions of cement and sand, was found to be nearly the same as for neat cement.

From the foregoing it appears that the total percentages of dry cement and sand required for different proportions of mortar vary so little that it will be sufficient to take the average, viz. about 57 per cent., an amount equal to 14·6 per cent. more than the volume of the mortar when set required to one volume of concrete.

In another case, 3·85 cubic feet of Portland cement, 11·54 cubic feet of sand, and 24·30 cubic feet of broken stone—total, 39·69 cubic feet, made 1 cubic yard of concrete, which equals a contraction of nearly 33 per cent.

The following examples of the contraction in volume of the dry materials when made into concrete are founded on some described in 'Spons' Mechanic's Own Book':—

In a concrete composed of 1 of Portland cement, 2 of sand, and 6 of shingle or broken stone, 1 cubic yard required, of dry materials, 27 cubic feet of shingle or broken stone, 9 cubic feet of sand, 4½ cubic feet of Portland cement or 3½ bushels—total, 40½ cubic feet; or a reduction in volume of 33 per cent.; and 25 gallons of water were used in mixing.

One yard of concrete of 1 Portland cement, 4·66 stone, 2 33 sand; 33 cubic feet of ballast, i.e. stone and sand, and 4½ cubic feet of Portland cement; total, 37½ cubic feet, or a reduction of 28 per cent. 30 gallons of water were used.

At Chatham Dockyard, a cubic yard of 1 of Portland cement to 12 of gravel concrete, required 32 cubic feet of gravel before shrinkage, 2 cubic feet of Portland cement or a reduction of nearly 21 per cent. 50 gallons of water were used with it.

At Cork Harbour Works, a concrete of 1 of Portland cement to 8 of stone and sand required 27 cubic feet of stone broken to $1\frac{1}{2}$ inch gauge, 9 cubic feet of sand, and $4\frac{1}{2}$ cubic feet of Portland cement, to make 1 cubic yard, or a reduction of 33 per cent.

At Portland Breakwater Fort, the stone being used in two sizes and the mortar mixed separately, 14 cubic feet of stones broken to a $3\frac{1}{2}$ inch gauge, 14 cubic feet broken to a $1\frac{1}{2}$ inch gauge, 10 cubic feet of sand, and 5 cubic feet of Portland cement, made 1 cubic yard of concrete, showing a reduction of 37 per cent. This increased reduction is not caused by shrinkage upon mixing with water, but from the smaller stones fitting in the interstices of the larger.

What are called magnesian cements have been referred to in Chapter I. The chief danger of an excess of magnesia in Portland cement is that hydration causes it to expand, and it is especially dangerous when hydration is deferred and any expansion subsequently takes place in the work, causing dilatation and disintegration of the concrete.

Some experiments made by MM. Durand Clay and Debray on the expansion of Portland cement made with cement mixed with calcined magnesia, and subsequently reburnt, showed that the expansion of such cement was considerable, and more rapid in summer than in winter. When samples of cement were immersed in water containing 0·6 per cent. of sulphate of magnesia, the expansion was greater than when it was exposed to river-water. A number of experiments were made with

well and imperfectly burned Portland cement; the latter increased more rapidly. When, however, a dilute solution of magnesia was used instead of river water, the ratio of expansion was reversed.

Some failures of concrete structures by expansion have been proved by M. Lechartier to result from an excess of magnesia in the cement, owing to its affinity for water: a white exudation being the result of such excess and cracking and flaking of the surface. A linear expansion of as much as 4 per cent. has been noted in cement made from magnesian limestone.

It may happen that a process of manufacturing, without extra cost, may be invented so as to render innocuous an excess of magnesia in cements, for it has been occasionally used as a cementing agent, and recently by exposing it to the action of carbonic acid gas refuse magnesia salts, the by-products of the manufacture of potass, have been employed as a cementing agent, and as a stucco, under Dr. Grundmann's process. However, good Portland cement, of English manufacture, does not usually contain more than about 0·33 to 1·00 per cent. of magnesia, and as from 0·60 to 0·90 is a usual proportion, it is advisable to not exceed that quantity. Good German Portland cement has from about 1 to 3 per cent. in it.

Mr. Harrison Hayter has recommended that Portland cement should not be used if it contains more than 1 per cent. of magnesia, and considers that there should be no carbonate of lime in it.

CHAPTER IV.

TESTING PORTLAND CEMENT.

Cohesiveness and adhesiveness—Precautions in testing—Variableness of quality—General tests—Cement and sand test—"Flying" cement—Specifications, &c.

Although tests and experiments are generally made to ascertain the tensile and compressive strength of the cement, in work, the strain upon the concrete, owing to unequal bearing and loading, irregular settlements, &c., is not necessarily directly tensile or compressive, but is frequently a shearing and transverse strain. Inasmuch as the compressive strength of cement is very much greater than its tensile strength, and apart from other reasons, the latter is the better general test; but its adhesive power to the aggregates should also be known, as that shows the true cementitious value of the cement, which is less than the tensile strength.

No normal test of the composition, strength, and durability of Portland cement has yet been decreed by English engineers, but some standard rules exist in Germany, France, Austria, Sweden, and Russia, and recommendations in the United States of America; but it should not be assumed because certain countries have adopted standard tests that nothing more is required to be ascertained respecting Portland cement,

and that there is no occasion to attempt to improve its quality; neither should it be taken for granted because the Portland cement is good that necessarily the concrete made with it is the same. As the strength of cement concrete is greatly dependent upon the adhesion of the cement to the aggregates, it is important to know its cohesive power when mixed with sand, and its adhesiveness to the stones forming the gravel, and also to any material likely to be used in the concrete, or attached thereto. If cement possesses great cohesiveness, it does not follow that it has the same power of adhesion to any substance. This is a point generally disregarded in standard tests, which take into consideration the strength of the pure cement, and when mixed with three parts of sand; but omit a test of its adhesiveness to other substances, which constitutes its true cementitious value; for although the tensile test of cement when mixed with sand proves its adhesive power to that substance, it does not necessarily show its adhesion to the stone forming the gravel which may be of a different character to the sand. The sand test only partly meets the case, although it is of great value. It was established to ascertain the adhesive or cementitious value of a Portland cement.

To effect a reliable test of Portland cement requires care, as the strength of test briquettes is governed by many circumstances. Among others may be named the following, each of which should be considered. They are not named in their order of importance, as that would be most difficult to determine.

The age of the Portland cement after grinding.

Whether the cement has been properly air-slaked.

Whether a skilled operator, accustomed to testing and making the briquettes, is employed.

The amount of residue after the cement has been sifted.

Whether the briquette mould was filled at one operation, and all air-bubbles removed.

The method of filling the briquette mould.

Whether the briquettes are made by the same operator, the same day, under the same conditions.

The time occupied in gauging the cement and filling the briquette mould.

Whether the mould is shaken, or tapped, to make the briquette more dense; or filled and firmly pressed by a trowel, or by other means.

The amount of water used in mixing.

The quality and character of the water used in mixing, for the soluble constituents in it may interfere with the setting; therefore it should be of the same character as that to be mixed with the concrete.

The temperature of the water.

Whether the briquettes are kept damp by wet cloths, or in a damp atmosphere, or kept dry, or in water.

The temperature of the setting room.

The temperature of the testing room.

Whether the cement is hand or machine mixed.

Whether the materials are mixed when dry several times before being mixed in a damp or wet state.

The method of gauging the dry cement.

The season of the year the test is made, unless the testing room is kept at a uniform temperature.

The nature of the slab upon which the briquettes are made, whether it is impervious or porous.

The method of removal of the briquette from the mould.

The area of the breaking section of the briquette.

The form of the briquette, and the proportion of its periphery to the area of the breaking section.

The length of time elapsing between the setting and the testing of the briquette.

The position of the strain as regards the breaking section of the briquette.

The nature of the strain, whether it is suddenly or gradually applied.

The time occupied in applying the strain and in making the test.

The form of clip for holding the briquettes.

Whether the clip is hung upon pivots to prevent cross strain.

The equal, or unequal, bearing of the clips on the briquettes.

Whether the moulds are perfectly clean and dry, or wet, before the cement is deposited.

Whether the mould is of iron or brass, or wood, and placed on an iron plate with damp blotting-paper interposed to prevent adhesion.

From the preceding brief compilation of some of the matters which affect the testing of cement, although distinct from its composition, it may be readily imagined that a rich field for controversy is presented; and it may be doubted if any other material largely used in engineering structures requires in testing such constant

observation and assiduous attention; hence the importance of knowing that any experiments have been properly conducted. Of course such laboratory tests will give higher values of strength than those made from material mixed in bulk on the work.

The object of chemical and mechanical tests is to discover defects in a Portland cement, to determine its quality, and to ascertain its strength and durability when mixed with sand, &c., as in mortar or concrete. Mechanical and chemical tests should be made, as a Portland cement may satisfactorily pass one kind of test, and yet not be of a sound, durable nature. On large works, a testing room with the necessary special apparatus is usually provided, but on small or scattered works such as railways, scientific tests may from various reasons not be possible; in such a case, a chemical analysis should be supplied with each delivery, and careful air-slaking and certain simple tests should be made in lieu of a more scientific determination of the quality of a Portland cement.

In France, since 1885, specifications for Portland cement for many important works demand, in addition to the usual tests, the inspection of its manufacture, and the frequent analysis of the raw materials. The latter is one which might be demanded, but as to the desirableness of an inspection of the manufacture, as it may be regarded as a kind of espionage, it is improbable that it will be generally adopted in this country, for if, during inspection, there was no demur to the method of production, and the right to afterwards reject a cement was not waived or qualified, although the Portland cement

was manufactured almost under the tacitly direct sanction of the engineer or buyer, disputes would be not unlikely, or a somewhat strained state of affairs. Nevertheless an expert by an occasional visit would soon discover whether a manufactory was or was not scientifically and properly conducted. However, such a desire to inspect a manufactory has been met in the following way, for with a view to ensuring the quality of their Portland cement, The Reliance Portland Cement Company, Limited, of Strood, near Rochester, have introduced a system, which should commend itself to all users of Portland cement. They have made arrangements for its manufacture under the immediate supervision of Mr. A. E. Carey, M. Inst. C.E., Fellow of the Chemical and Geological Societies; thus a guarantee by an expert and engineer, who has had much experience of Portland cement concrete in marine and other works, is presented that the Portland cement is properly manufactured and suitable for engineering purposes, and a certificate as to quality is given in the form shown on the following page.

It should always be borne in mind that tests conducted in a laboratory are performed to the greatest advantage, and that concrete in bulk made with the cement mortar seldom gives such good results, therefore allowance should be made. Portland cement experiments are also affected by the time that has elapsed since the cement was manufactured, and when it is taken from the outside and inside of a bag or cask it may give dissimilar results, therefore it is advisable to empty the contents of a bag or barrel and thoroughly mix it before

I hereby certify that ______________________ of Cement shipped per ______________________ to the order of ______________________ marked ______________________,
has been tested by me with the following results:—

TENSILE STRENGTH.

Neat Cement at 7 days in Water.	Lbs. per square inch section.	
Average ..		

Specific gravity ______________ Weight per bushel ______________

Lime tests ______________ Proportion of water by weight used in gauging ______________

Percentage of residue on 50 by 50 mesh. ______________ Remarks ______________

Signed ______________

Date ______________

taking any cement to be tested, for, in the work, the practical and reliable strength is the least, not the greatest strength.

With care in every other respect, different results can be attained by ramming Portland cement into a mould and mixing it with a minimum of water, and merely lightly pressing it with a trowel and mixing with the same quantity of water that will be required when the mortar is mixed with the aggregates. The chief aim should be to endeavour to make tests similar to the

actual conditions of work or those under which a concrete will be placed. By well directed manipulation, tests might be made to give various results, almost at the will of a skilled operator.

The cube is a simple and easily prepared form for experiments to ascertain the compressive strength, and provided the load is equally distributed it may be considered reliable. The type of test briquette most approved is that of the hour-glass, as there are no abrupt bends or shoulders. The present tendency is to reduce the sectional area at the centre to 0·75 or 1 square inch, but formerly it was considered that briquettes used for testing purposes should have an area of not less than 2 to 2½ square inches, as smaller test pieces, although more convenient when many tests have to be made, are found to give too great strength per unit of area; but it has been pointed out that when the strength of the breaking area of each briquette of a different size is divided by its periphery, the strength per unit of area is nearly identical. The breaking area of cement test briquettes should be large rather than small, although sufficient cement can only be simultaneously gauged for one or two moulds instead of five or six, as then the minimum and not the maximum strength is likely to be ascertained, and an area of one square inch is sufficiently small and easy of manipulation, and will probably become the type for tensile tests. The strain at the outside of a test briquette is considered to be somewhat greater than at the centre of the section. In all testing machines, the principal object to attain is to firmly, evenly, uniformly and vertically hold a

briquette, and to ensure that it cannot alter its true position.

Briquette testing may be conducted in such a refined manner as to be only valuable for *comparing* the strengths of different Portland cements. For reliable comparative results the tests must be made under identical conditions. On important works, or in any place where Portland cement is liable to be variably strained, shearing, cementitious, and compressive tests should be made, as well as those to ascertain the tensile strength. When exposed to the action of the atmosphere, and not submerged, cement briquettes which show a serrated fracture it has been found have been injured by desiccation consequent upon contraction. A purely hydraulic cement mortar, when broken, has a shelly appearance.

To show the variableness of the quality of Portland cement, a difference in strength sometimes occurs between each cargo, and even in the same shipment or delivery; consequently a regular system of testing should be instituted. It is now agreed that a simple test of the strength and character of neat cement is not necessarily a guarantee of similar powers when it is incorporated with sand, and therefore tests are specified when the cement is mixed with sand, usually in the proportion of one part by volume of Portland cement to three parts of sand, and the sand should be similar to that to be used in the work. The sand test is, and should be, principally relied upon, and it has the distinct advantage that as usually 28 days are allowed before the test, there is not the inducement or necessity to overlime a Portland cement. Neat cement

trials should only be considered as showing the uniformity of the strength of different deliveries, and as a check on other tests, and not as an absolute indication of the value of the cement in work; but if the neat cement tensile tests are satisfactory, and the sand tests the reverse, it may be assumed that the sand is bad and not the cement. It is also advisable to test the cement in its unsifted state, as supplied by the manufacturer, in case the sifting on the works may not be properly done.

A mere test of neat cement after being 7 days in mould cannot be alone trusted; 28 days should be the least period to elapse from the filling of the mould to the final test, which, if it gives the specified strength and shows the desired character, can be taken as a reliable certificate of the quality of the Portland cement. Of course additional tests should be made between the time of setting and the final test, which latter must be satisfactory or the material should be rejected. Tests with neat cement should be made, in order to check the trials of cement and sand mixed, and the rate of gaining strength should be noted in all cases. The value of a regular increase in strength from 7 to 28 days, and of the 28 days' test is great, as it reveals the character of a Portland cement and brings to light any important defects; but 7 days is too short a time to prove that a Portland cement is sound, durable, properly constituted and manufactured. If a Portland cement satisfactorily complies with the conditions of tests named there is scarcely the slightest fear that it will seriously deteriorate.

The tensile strength of neat Portland cement of good quality at 7 days old, one day in air, remainder in water, is usually from 300 lbs. to 400 lbs. per square inch, and the increase of tensile strength between a 7 and a 28 days' test is about 40 to 50 per cent.; but it varies considerably, and should not be less than 25 per cent. A few years ago a high tensile strength within 7 days was frequently demanded, but this has now generally been agreed as inviting a manufacturer to deliver an over-limed Portland cement. Not a few experienced engineers consider 250 lbs per square inch a sufficiently high test at 7 days, and some even 225 lbs., but sound, durable Portland cement can be obtained to stand a much greater strain. The minimum required by some French Government specifications is 285 lbs. If a Portland cement must be tested for tensile strength at 3 days, 200 lbs. per square inch is quite high enough, and such a Portland cement would probably bear about 350 lbs. at 7 days, perhaps more, and this is about the average tensile strength of ordinary, good, sound, non-flying, and durable Portland cement, and it is not advisable to much exceed it, unless the weight of the Portland cement is moderate or low, and it is ascertained the material is thoroughly sound in all other respects. In thin work, such as bridge abutments or wingwalls, archwork, piers, and retaining walls, 350 lbs. or a higher test may be preferable, and its full strength, which should be maintained, is then required at a comparatively early date, such as 28 days. It has been suggested that a maximum tensil estrength in 7 or 28 days is not the best test, but that a minimum strength on a certain

day should be required, and a fixed increase of strength between defined periods.

It should not be overlooked that it is possible to require too high a tensile strength, especially at an early date, and that the tensile strength, although important, is not all that should be desired in a good and sound Portland cement: for instance, over-limed Portland cements will give a high tensile strength at 7 days, but be dangerous, especially in immersed work; as the excess of lime in the cement must, sooner or later, become slaked by moisture, and then the mass will expand, or crack, and the concrete probably be more or less disintegrated. A moderate tensile strength, say about 300 lbs. to 350 lbs. per square inch at 7 days, and increasing with age, is to be desired, and not a high tensile power attained within a few days of mixing and not afterwards increased; but 7 days is too short, and a 28 days' test is now conceded as the least for a really crucial test, although the strength at 7 days should be ascertained to know the rate of increase of strength, and unless under unavoidable circumstances a 28 days' test should be required before a Portland cement is accepted or allowed to be used in work. Portland cement of a dangerous character, especially in marine work, might satisfactorily stand, and has, a 7 days' test, but at 28 days it will show signs of deterioration, and the decrease of strength will probably continue until the cement is worthless, having lost its cementitious value. An almost certain indication of a bad cement is one that possesses a greater tensile strength at 7 than at 28 days, and such a cement should not be

used, as all good Portland cements should augment in strength in about the proportions previously stated. About 500 lbs. to 550 lbs. per square inch at 28 days is sufficiently strong. The minimum required by some French Government specifications is 498 lbs. per square inch at 28 days, and at least 640 lbs. at 84 days, but if in 28 days the increase in strength above that at 7 days does not exceed 71 lbs. per square inch, then it must be 782 lbs. in 28 days, and if not then attained, it must be exceeded in 84 days. In these specifications, puzzolana cements, or those made of lime mixed with slag, are expressly excluded. In the German standard rules, the crushing strength after 28 days' setting is fixed as the final test, the 28 days' tensile strength being used to determine the quality of the cement as delivered.

Baron Rochemont, in a series of experiments extending over the long period of 17 years, found that the tensile strength of neat Portland cement attained its maximum after a few months, and in the experiments was about 400 lbs. per square inch; that it decreased during several years, and subsequently improved; increased for a few months, then gradually decreased for 5 to 6 years to about 170 lbs. per square inch, and steadily improved for another 12 years at the rate of about 9 lbs. per annum, 17 years being the limit of the test period, the tensile strength then being about 280 lbs. per square inch. With Portland cement mortars the decrease was much slower, and the increase appeared to be larger in proportion to the less richness of the mortar.

The importance of testing the cement when mixed with sand cannot be over-estimated, because tests with

neat cement, which is seldom used in work, do not prove that the cement is finely ground, but those with cement when mixed with sand in the proportions previously described, show if the cement is finely ground, or has particles which are not equally or thoroughly pulverised; and it has been shown by reliable experiments that the coarse particles, or residue from the sieve, in their unground state, have little more than the strength of sand. The test of cement mixed with sand should never be omitted. In addition, coarsely ground cement when mixed neat gives a higher tensile strength than fine cement, but when mixed with sand the reverse is the case.

Another important feature of the sand test is that the ultimate tensile strength of neat Portland cement does not increase with its fineness beyond certain limits, but when mixed with sand it increases decidedly, and the finer Portland cement will almost invariably possess the greater strength when used in mortar, i. e. with sand. It also is an indication of its cementitious strength. The tensile strength of 1 of Portland cement to 3 of sand test briquettes varies from about 90 lbs. to 140 lbs. per square inch, 120 lbs. being about the average in 7 days, and about 140 lbs. to 220 lbs. per square inch at 28 days, about 180 lbs. to 200 lbs. being the average; but, of course, the variation of strength will be considerable, and more so than in neat Portland cement, as not only may the latter be different in quality, but also the sand, and unless a standard sand is fixed any values given can only be approximate. In any case, however, from 7 to 28 days a regular increase in strength

from the minimum should be required, and not less than about 40 to 50 per cent. The German standard rules are that the minimum tensile strength of mortars consisting of 1 part of slow-setting Portland cement + 3 parts standard sand, by weight, which has hardened for 1 day in air and then for 27 days in water, shall be 227·5 lbs. per square inch in tension, and 2275·6 lbs. per square inch in compression. This standard clean quartz sand is exceptionally good, and is seldom equalled in mortar mixed in bulk on works and is described in the chapter on "Sand, Gravel, and Stone."

With respect to the adhesive strength, which is the cementitious value of Portland cement, the most complete experiments yet made known are those of Mr. Mann, who has made upwards of 1200 separate tests.

The average cohesive strength of the neat Portland cement tested was after 7 days 425 lbs. per square inch. The average adhesive strength of the same neat Portland cement being 61 lbs. per square inch, and 84 lbs. per square inch, after 7 and 28 days' immersion respectively. The test pieces to which the Portland cement was attached were sawn, close-grained limestone.

The general averages of sifted fine cement through a silk sieve, 176 meshes per lineal inch, meshes ·004 inch square, were 78 lbs. per square inch at 7 days and 93 lbs. per square inch at 28 days for adhesion of mortar. The unsifted cement gave a general average of 57 lbs. and 78 lbs. per square inch at 7 days and 28 days respectively. The Portland cement was of good quality and possessed a high cohesive strength.

An analysis of these experiments shows that there is no general ratio between the adhesive and cohesive strength of Portland cement. In ten tests, 5 at 7 days, 5 at 28 days, the ratios ranged from 5 (cohesive) to 1 (adhesive), to 9 (cohesive) to 1 (adhesive) in the case of 7 days' tests; and 3 (cohesive) to 1 (adhesive), to 5 (cohesive) to 1 (adhesive) in 28 days; therefore, 7 days' tests are unreliable. The cohesive strength remained nearly stationary, but the adhesive strength increased very considerably.

Mr. Mann, in the 'Minutes of Proceedings of the Institution of Civil Engineers,' vol. lxxi., gives the following adhesive strength specification, which is the first one published, drafted solely with regard to the adhesive strength of Portland cement.

"The Portland cement shall be ground so that not more than 45 per cent. shall be stopped by a No. 176 silk sieve, and its average adhesive strength after 28 days' immersion shall be as follows:—

"Cement passing No. 176 sieve, not less than 95 lbs. per square inch.

"Cement as supplied for use, not less than 75 lbs. per square inch.

"Six tests being employed in each case."

The No. 176 silk sieve per lineal inch gives 30,976 meshes per square inch, the meshes being ·004 inch square, which corresponds in width with a B.W.G. No. 36. Sawn, close-grained limestone can be the test piece for adhesive purposes. The cement as supplied for use means mixed without sifting, and as delivered by the manufacturer.

Mr. Grant has given the adhesive strength of a mortar consisting of 1 of Portland cement to 2 of sand to ordinary bricks after 28 days as from 15 to 30 lbs. per square inch.

In Germany, the hardness of cement has been tested on Dr. Böhme's system, The test blocks are pressed against a revolving disc, each block being tested, the revolutions, speed, and other conditions being similar, the loss of weight in a given time determines the relative durability and hardness. Some discs of Portland cement and sand were mixed in different proportions by weight and tried, with the following results:—The loss by abrasion was found to be the least in mixtures of 1 of Portland cement to 1 of sand, and 1 of Portland cement to 2 of sand, and was ascertained by carefully weighing the test pieces. The abrasion generally increased after a 1 of Portland cement to 3 of sand mixture was reached.

Tests to ascertain whether a Portland cement is likely to "blow" or "fly" should always be made, and as they can be made very easily and most inexpensively there is no occasion to omit them, in fact, they should be considered as absolutely essential; and it is always advisable to make cement and sand tests, at any rate in the proportions they are to be used as mortar on the work as well as with the neat Portland cement. Such a test applies not only to expansion, but also to contraction. The expansion and contraction is shown by puffing or swelling of the pat at the edges, hair cracks, slight cracks, and fissures. As a rule, dark grey Portland cements give the best results in such tests, and

generally in all other respects. All such test pats become hard and impervious to water on the outside first, because of the exposure to the air and proportionate evaporation of the water.

Some tests adopted to ascertain whether a Portland cement will "blow," "fly," be unsound, or is over-limed are now mentioned.

The standard German test for "flying" of cement may be briefly stated to be as follows :—A neat Portland cement pat is mixed on glass, and is allowed to set for twenty-four hours before it is immersed in water, during which period it is kept moist and in the shade, the cake and glass are then submerged. If the cake crumples or cracks at the edge after one or more days' immersion, the cement is considered a "flying" cement. Other tests by means of boiling and baking are sometimes applied.

A test drafted after very numerous experiments, at the direction of the French Government, is carried out by pats 3·15 to 3·94 inches in diameter, and 0·787 inch in thickness at the centre, and sloping down in all directions so as to make the edges as thin as possible. The pats are placed on glass and immersed in sea water having a temperature of from 59° to 64·4° Fahrenheit. They must not crack or bulge, or show any signs of it.

In all the following pat tests, after 24 or 48 hours or 7 days, they should not show any signs of cracking at the edges, which should be perfectly true and sharp, expanding or warping, nor have a crumpled or swollen surface, nor should any part of the pat rise from the glass or slab, and the cement should adhere to it.

The appearance of a pat when broken should be of a dense even-grained and uniform texture.

Pats of neat cement, and balls of cement and sand, can be immersed immediately after mixing in sea or fresh water. Thin pats of Portland cement can also be poured on glass, and be allowed one day to set, and then be submerged in either sea or fresh water; or a pat of about an eighth of an inch in thickness, and not more than that at the edges, can be placed on glass and immersed directly after mixing, or some can be kept in the air, 7 days being allowed before inspection. Another simple test is to fill a glass bottle with Portland cement, mixed with the proportion of water to be used in the work, and if the bottle is uncracked after a day or so the Portland cement may be considered sufficiently free from any tendency to "fly"; but a longer test should be made if possible. It can be inspected occasionally, so as to observe, should it expand or crack, the hour at which it did so.

A test made by Mr. Faija, to decide within twenty-four hours whether a cement will "blow," was to subject a small pat of it, immediately on gauging, to a moist heat of about 90° Fahr., and when set, which will probably be within two or three hours, to keep it in a warm bath at a temperature of about 100° Fahr., but not more. He found that good and properly aerated cement did not "blow" at these temperatures, but an improperly made and very fresh cement will, sooner or later. The pat should be perfectly sound, and not swollen or blown in any way to be good cement. A test should also be made with a pat of cement

when the latter has been air-slaked for two or three days.

Prof. Tetmajer has suggested that Portland cements which stand the following tests may be relied upon to resist atmospheric influences, especially that of carbonic acid. Slabs should be made of about 4 inches diameter and $\frac{13}{32}$ of an inch in thickness, and after setting be subjected to a temperature of about 120° Cent. = 248° Fahr., for from 3 to 4 hours in a *drying* chamber.

Violent tests in nearly or quite boiling water have been occasionally adopted, but their value has yet to be proved, and a test more in accordance with that the Portland cement will be subject to in a structure, although more severe, is to be preferred, as such a boiling bath test, if it be a really reliable test at all, is more interesting than instructive or valuable. It will be noticed Mr. Faija limits the degree of heat in the bath to 100° Fahr. A test by heat in a dry or wet state is altogether different to placing a pat in boiling water and agitating it to some degree of destruction in the hope of learning something from the remains.

As the compressive strength of Portland cement is very much greater than its tensile or adhesive strength (see Chapter X., "Table of Strengths"), unless the concrete is to be used for an exceptional purpose it is generally considered unnecessary to ascertain its power of resistance to compression, but the new German standard rules require compression tests as previously described in this chapter.

If other tests are considered desirable besides those named they should be in the nature of experiments as

to the strength of the concrete or cement, as a beam or girder, although the shearing strength of cement is usually considerably greater than its tensile power.

At the Royal Technical High School at Prague some experiments were made on the crushing strength of Portland cement mixed in various proportions with sand, and tested partly in the form of cylinders and partly in that of cubes. The results were as follows:—

Composition.	Cylinders.		Prisms.		Percentage of strength of prism to cylinder.
	Age.	Crushing Load.	Age.	Crushing Load.	
	Days.	lbs. per sq. inch.	Days.	lbs. per sq. inch.	
1 part cement, 1 sand	378	47,600	312	33,600	72
1 „ „ 2 „	387	48,400	312	30,600	62
1 „ „ 3 „	311	25,700	310	22,000	85
1 „ „ 4 „	120	11,400	310	8,000	70

The cylinders stood the ultimate load several hours before actual crushing, while the prisms crushed almost immediately. It was considered form has a considerable influence on the resisting powers of cements, but probably the difference is in great measure due to its being much more difficult to bring the strain equally over all parts of a prismatic than of a cylindrical section.

With reference to specifications of Portland cement, almost every practical variety of test for fineness, weight, strength, and time of setting has been particularised. Doubtless, gradually a uniform specification, or one nearly so, will be established. At present the differences are noticeable, for they are as much as

about 300 per cent. in the requirements as to fineness, 6 to 10 per cent. as to weight, and 50 per cent. or more as to strength. There is uniformity only in the time of testing, but in the last few years the differences have been reduced, and in a short time it would seem that a state approaching uniformity may be attained, except as regards fineness and the percentage of residue on the sieve after sifting. Under these circumstances the best course, bearing in mind the particular features of each case, is to intelligently follow and compare the specifications of the acknowledged authorities on the subject, which in all probability will be amended from time to time as fresh light is shed on so complex a material. The entirely independent drafting of a correct Portland cement specification demands much technical knowledge, intimate familiarity with the material in the test-room and on works, and almost lifelong experiments.

CHAPTER V.

THE SETTING OF PORTLAND CEMENTS.

Quick and slow setting Portland cements—Setting under hydrostatic pressure, in compressed air, and frosty weather.

For engineering works it is generally desirable that cement or concrete should, within a short time of its deposition, nearly attain its greatest strength, which should be maintained; and with respect to the time required for setting, cement concrete in one situation may be required to harden quickly and have immediate strength, and it may be absolutely necessary to use quick-setting material, in tidal work for instance, even if the ultimate strength is thereby decreased. On the contrary, it may not matter that the cement should set quickly. The hardening of slow-setting cements is generally considered more trustworthy than that of quick-setting cements; but seasoned cement will take longer to set than cement fresh from the manufactory, and those with the smaller residue will usually set the quickest. The process of hardening commences after setting has taken place, and continues to proceed for years. As a rule, it may be considered that quick-setting cements are inferior in ultimate strength to slow, or moderately slow-setting, and that heavy Portland cements are slow-setting. The reason is believed

to be that while the mortar or concrete is setting, and during the first stages of induration, liberating lime, a mechanical action of settling is in progress amongst the particles, which ceases when the concrete or mortar is set, leaving the chemical process, which is regarded as the formation of a hydrous compound silicate, to complete the induration, and the longer this mechanical action proceeds the denser the material becomes, and, therefore, the stronger. The setting of a hydraulic cement has been attributed by M. Fremy to two chemical actions ; 1, to the hydration of aluminates of lime, and, 2, to the action of hydrate of lime upon the silicate of lime and the silicate of alumina and lime which exist in all cements, and in this case act as puzzolanas. A true cement has been described as a substance which solidifies its water of hydration without going into a powder. Generally a light, quick-setting Portland cement does not retain sufficient moisture to enable the crystallisation to be properly effected. Hence, a Portland cement of a high specific gravity is required in order that it may become thoroughly indurated, and this is especially necessary in all works exposed to sea water, or submerged.

Perhaps, for general engineering purposes, a Portland cement possessing moderate strength and comparatively quick-setting properties is most useful, and provided a moderate tensile strength, say 300 lbs. to 350 lbs., is specified at 7 days, many experiments demonstrate that such a Portland cement will ultimately be a very strong one and increase in strength by age, and that an over-limed Portland cement is usually comparatively slow-setting.

Cement may occasionally be required that will set in a few minutes, as Medina cement, for stopping leaks, and other purposes where almost immediate solidification is required; but about the quickest time in which Portland cement for general engineering purposes should set is one hour. It is sometimes specified that concrete is to be used freshly mixed, a clause which is open to various interpretations. It is better to state that it is to be mixed and used when and as may be directed, because in thick walls it can be at once deposited direct from a mixer, but in thin work more time must elapse, and especially in using a cement mortar for brickwork or masonry, an hour or more may be required to use a skip or measure of Portland cement mortar, and apart from a mere laboratory test of the time in which a Portland cement should set, in work in general, perhaps one hour is quite quick enough, and considering that a better connection can be made between masses of concrete that have not set and those that have, a rather slow-setting Portland cement is to be preferred to a very quick-setting, and the selection must depend upon the character and special circumstances, which necessarily vary.

The test of setting required by a specification drafted, after thousands of experiments, by order of the French Minister of Public Works, for harbour work, is that a portion of cement is to be made into mortar and filled into a cylindrical box of metal 1·575 inch in height, and 3·15 inches in diameter. The mortar is then shaken down by a few gentle blows, and the water which rises to the surface is allowed to remain. A weighted needle of 10·58 oz., and with a square section

of 0·00155 square inch, equals about $\frac{1}{25}$th of an inch square, is suspended over the box by means of a cord and pulley, and the initial set is considered to have taken place when the needle fails to penetrate the whole depth of the mortar if lowered gently upon it. The cement is said to have set finally when its surface will support the needle. Any cement commencing to set in less than 30 minutes, or setting finally in less than 3 hours, is to be rejected, and the final set must have taken place within 12 hours. In each case the time is reckoned from the moment the water is poured upon the cement.

In the new German standard rules, the time of setting of a slow-setting Portland cement is fixed at two hours, and it is stated that in all tests the time of setting should be mentioned, because the strength of quick-setting Portland cements is lower than that of slow-setting cements.

In the specification of the Portland cement for Putney Bridge, over the Thames, it was stipulated that the neat cement must not at any season of the year set in less than an hour.

With respect to the time in which a test cake of Portland cement should set, when it is to be used in thick masses, it is well if a thin cake sets in about one hour, but not much less, and if Portland cement, when made neat into a thin cake, allows the impression of a finger-nail after two hours if kept in air, it may be considered slow-setting, but it will generally be the stronger and more reliable cement, and a strong one may take fully an hour more than a weaker.

The time required for setting, or hardening, can be

accelerated by using only sufficient water to enable the cake to be made, and by compressing the same. In warm dry air, cement will usually set quicker than in cool damp air, or when the air is saturated with moisture; it also sets considerably quicker in air than in water, and finely sifted cement also sets faster both in air and water than ordinary unsifted cement.

Mr. Mann's experiments upon the adhesive strength of Portland cement show that the quick-setting cements, with but few exceptions, had more adhesive strength than the slow-setting, whereas the slow-setting had the greater cohesive strength.

The time required for the setting of neat Portland cement varies very greatly, being from a few minutes to some hours. Cement frequently sets in from about thirty minutes to twelve hours, and more often from one hour to seven hours; one to four hours being the usual interval.

Quick-setting cements generally increase in temperature shortly after being mixed, sometimes as much as 10° Fahr., and then return to the normal temperature, but slow-setting remain practically the same. Because a cement shows high compressive or tensile strength at an early date after it is mixed, it should not be considered that it is an undoubtedly good cement; and it is well to remember that its strength has no uniform relation to its adhesive properties.

When cement cracks and blows on being placed in water, it sometimes results from an excess of chalk, one of the forms in which lime is found, producing what is called "free" lime in the cement; it may also be

caused from an excess of clay. Cement that shows these symptoms should not be used in the permanent work. High tensile strength is generally obtained by an increase of chalk, which, when in excess, will make the cement slower setting, but it will be liable to crack and "fly." Cement with an excess of clay sets very rapidly, but does not so completely indurate, is weaker, and attains to only a moderate degree of hardness, and loses to some extent the hydraulic properties of the excess of chalk cement.

It has been found that concrete will not set under hydrostatic pressure, and that the water pushes its way through the interstices of the stone before the cement has time to harden sufficiently to resist it. With respect to the setting of concrete in compressed air, the upper surface in contact with the air-pressure sets very quickly, so that the rest of the mass derives very little or no benefit from the air-pressure, unless means are taken to bring it in contact, or opposition to, the force of water. Small vertical pipes leading downwards to the bottom of the concrete, and placed within 1 foot of each other over the whole area of the concrete, have been used to obviate this difficulty. It is advisable in all cases to test the setting powers of any concrete to be used under a similar pressure to that which it will have to sustain when being deposited. General experience seems to show that concrete laid down under compressed air sets quicker and slightly increases in strength provided it is deposited in thin layers, which allow any excess of water to escape.

With respect to the effects of frost upon the setting

of Portland cement, if concrete must be used in frosty weather, experience has shown that it should be mixed under cover, and not deposited in a frozen condition or on frozen concrete, and that in order to obtain adhesion with any mass previously deposited all ice must be removed and a steam hose be turned on so as to thaw the surface, which should afterwards be brushed. Frost does not appear to affect concrete below a few inches from the surface, and, therefore, it should always be closely covered with planks, tarpaulin, mats, or straw, if an unfinished structure must be left open for some hours.

Experiments have shown that the loss of strength varies in the case of neat Portland cement according to the degree and number of days of exposure. It amounts to about 20 per cent. at 7 days, to 40 per cent. at 28 days, and with Portland cement mortar about 40 per cent. at 7 days, to about 60 per cent. at 28 days. The temperature varied from freezing point to a few degrees below zero Fahrenheit. The loss of strength depends, so far as the nature of the concrete is concerned, upon the quickness of setting. Hence neat cement suffers the least, and quick-setting Portland cement is to be preferred under such circumstances.

As Portland cement mixed with hydrochloric acid, or with a saturated solution of soda, sets at once and becomes hard, some experiments were made in Austria to see if in such extremely low temperatures as those which occurred in December 1889, when the thermometer registered 31° to 16° below zero Fahr., damaged the Portland cement. When it was taken

from the cold and put into a hot oven for 3 hours it was found the extreme cold had no disadvantageous effect on the setting qualities. 1 of Portland cement was mixed with 1 portion of lime and 3 of river sand, about $1\frac{1}{4}$ lb. of crystallised soda being used with the water.

Some other experiments made to ascertain the effects of frost on Portland cement and lime mortars mixed with fresh water, water containing in solution 2 per cent. of salt, also 8 per cent. of common salt, which is about the maximum so used, showed that when the test cubes were allowed to set in the open air, the temperature being at night 18° to 25° Fahr., that the fresh water mixed cubes fell to pieces under the pressure of the hand, and bricks did not adhere with such mortar joints. In the case of the 2 per cent. salt added mortar it could not be crushed by hand, and bricks were separated with some difficulty; but the 8 per cent. mixture could neither be crushed by hand, nor the bricks separated. The Portland cement mortar was stronger than that made from hydraulic lime.

Mr. Noble, on the St. Mary Canal between Lakes Superior and Huron, found that in the case of a 1 to 1 Portland cement mortar, and a 1 to 1 good natural American hydraulic lime mortar, both made in frosty weather, that the Portland cement mortar was perfectly sound a year after, but the hydraulic lime had been destroyed to a depth of 3 and 4 inches. In another example, although a considerable quantity of salt was used, the Portland cement concrete was completely frozen, yet it proved perfectly sound, although it had

to resist a 15-feet head of water. In another case, where the temperature was as low as 1·4° Fahr., a Portland cement mortar of 1 to $1\frac{1}{2}$ of sand, and 1 to $2\frac{1}{2}$ of sand, although the sand was warmed and large quantities of salt were added to the water, at a temperature of 1·4° Fahr., the mortar became frozen very quickly while being used, yet no difference could be noticed between that set in such frosty weather and that mixed at a temperature above freezing point. Other recent experiments by Mr. G. S. Morrison in America confirmed these, and showed that although the water in which the test pieces were plunged 24 hours after setting in the air became a solid piece of ice, on its melting again the Portland cement was found to be uninjured, but the American hydraulic lime fell to pieces. Mr. Shanahan, the Superintendent of Public Works, State of New York, used a larger proportion of Portland cement with a strong solution of salt for mixing the mortar, and never found that defective work had resulted.

CHAPTER VI.

SAND, GRAVEL, AND STONE.

Proportions, character, coarseness, form, and size—Gravel, stone, and sand, making good and bad concrete and mortar, &c.

There are two proportions of the gravel and sand used in concrete which should be ascertained before deciding upon the ratios of the mixture. They are :—

1. The quantity of sand required to fill the interstices between the stones in the gravel or shingle.

2. The contents of the interstices in the sand, which, however, are slightly less than the amount of cement required to fill them completely.

In the chapters, "Proportions of the Ingredients" and "Mixing Concrete," a method is described of ascertaining the proportions of cement and sand required to mix with the stone or shingle.

If the natural shingle or gravel varies in character every effort should be made to blend it and cause it to be uniform in order to obtain equal strength.

The reason that sand of a uniform character, mixed with the necessary smaller particles to fill the interstitial spaces, produces a more impervious mortar or concrete than sand of an unequal nature, having the interstitial spaces filled or not, as may happen, is that if properly mixed the grains become equally coated,

subside regularly, and the concrete is of defined character and of equal strength.

A simple way to find the proper proportions of gravel or shingle to sand is to screen the gravel or shingle and proceed to use the water-measure test, previously referred to, to ascertain the relative cubical contents of the stone and the sand required to fill its interstices; and here it should be named that the water must be gauged as it is poured into the measure, and not after that operation.

It is well if the amount of sand in the gravel or shingle in its natural state as excavated and delivered on the works is ascertained. To do this a certain volume or measure of gravel or shingle, preferably in a damp state, should be first thoroughly screened and the residue carefully kept, and then the screened gravel or shingle should be washed and the residue added to the other sand; on this having been done, the whole of the sand should be put into a measure; the water required to fill up the measure and gauged on delivery into the vessel will show by deduction from the total cubical contents of the measure the volume of sand in the measure; and a similar operation must be performed with the gravel or shingle, when the proportions of sand to gravel or shingle will be made known.

It is only necessary to remember the almost universal presence of sand in the earth to declare its variety, from the quartzite rock, millstone grit, red sandstone, &c., to that of mere "blown" sand, such as is contained in the low sweeping hills by the sea, or in the restless desert.

Sand varies in character very greatly, and is of different colours. It is found pure, and also mixed with every possible impurity, being any mass of fine particles of silicious rock, pure or impure, and consisting of minute concretions or fossils indissoluble by water.

Moderately hard sandstones, being those more often met with, contain a large or small admixture of clayey or calcareous matter; and greensands have green particles of silicate of iron in them.

Sand, upon which much friction from wind and water has taken place, seldom has any coating of metallic oxides upon it, and is more grey in colour. As a rule, the more vegetation found on sand rocks the more impure and argillaceous is the sand; and the loose movable sands of white grains and considerable fineness, bare of vegetation, are characteristic of sand in its unmixed state.

Sometimes a certain proportion of sand and gravel to Portland cement is specified without any reference to their character, except that the sand must be clean and sharp, and free from loamy particles, and pass through a sieve of about 400, and be retained upon a sieve of about 900 meshes per square inch; and the gravel be clean, and no stone to exceed a certain size; such as the stone to pass through a 2-inch ring, although sometimes Thames ballast, &c., is named, and river sand.

Considering the very varied character of sand and gravel it seems that more attention should be given to the particularisation of the sand and gravel, remembering the locality of the works in each case, and the

geological features of the district from which, for reasons of economy, the sand or gravel must be obtained. The value of it from an engineering point of view may be very different, even in a small area; and to be most particular as to the character and quality of Portland cement, and apparently regardless of that of the sand and gravel, although the latter may form about 85 to 93 per cent. of the volume before mixing, is hardly capable of vindication, especially as Portland cement concrete should be a monolithic mass, and the effect of sand is to retard the process of induration and to decrease the strength. Similarly with regard to gravel, for it can be obtained from almost every kind of rock, whether simple weatherings or boulders, worn, broken up, and rolled by mechanical attrition.

In important marine works an analysis of the sand should be made in order to determine the quantity of lime and magnesia in or upon it in the condition in which it will have to be used, or the sand can be washed to free it of magnesia, and most of the lime and alumina, so that it may be almost entirely consisting of silica insoluble in acids. Most sand contains, as well as the silica, alumina and peroxide of iron, lime, magnesia, &c. Sand which has a considerable percentage of lime, namely, from about 8 to 10 per cent., will generally in test briquettes have greater tensile strength than one with 2 or 3 per cent., or pure silicious sand, but it is not so trustworthy. However, sand is very seldom completely free from calcareous particles.

The sand should be as coarse as possible consistent with making fine mortar, and if it should be retained

on a sieve having somewhat fewer meshes than that specified, it should, within reasonable limits, not be necessarily rejected.

The character, degree of fineness, and the form of the sand grains affect the strength of the concrete. The sand should be free from all loamy or argillaceous matter, and that obtained from the hardest sandstone rocks should be preferred, which has its grains in a pure state, i. e. not coated with material that may be called a foreign substance, but quartzose sand is better, and probably the best is crushed granite, washed thoroughly clean, coarse, and of angular shape.

The shingle, gravel, or sand cannot be too clean and free from impurities, especially in thin work, and when combined with brickwork or masonry; but in large masses it may not be so important, although every effort should be made to cleanse it.

No sea-shells, which consist principally of carbonate of lime, with a small quantity of animal matter, or anything having carbonate of lime in or upon it, should be used, as there is no chemical action between it and the lime of the Portland cement. Sand should also be free from clayey, peaty, or earthy matter, vegetable fibre, or other impurities, and it should be purely silicious, and perfectly clean and sharp. It has been stated that the lime of the Portland cement gradually combines chemically with quartzose sand, but it can hardly be said that it has been proved, and it is denied by some authorities.

The deleterious effects of peaty impurities in the sand are well demonstrated by a case referred to in

'Dingler's Polytechnic Journal,' vol. cclxiii. A 1 of Portland cement to 3 of sand floor was made, and watered daily, but remained in a soft state. The Portland cement was blamed, but it was found the granitic sand had small brown grains, which were fragments of peat. The neat Portland cement set properly, and showed satisfactory strength, but when mixed with 3 per cent. of the sand it did not set. When the standard quartz sand was adulterated with pulverized peat, the 3 to 1 mixture did not set. It was supposed the humic acid combined with the lime of the cement, forming a compound which enveloped the particles of mortar and prevented setting.

Very fine, or fine sand, even if perfectly clean, should not be used for Portland cement concretes, or mortars, as by repeated experiments, and for the several reasons herein named, it has been proved to lessen their strength very considerably, even as much as 40 per cent. as compared with coarse sand. An explanation of which decrease in strength is, that fine sand in a given bulk has necessarily a much greater number of grains than coarse sand, and as there are more grains to cover with cement the difficulty of thorough incorporation is increased, and further it has been shown by Professor Lewis that, under a microscope with a power of 110 diameters, each grain of sand is surrounded by a small film of cement, and that vacuities exist between the particles of sand and the cement; it is, therefore, obvious, the fewer the grains the fewer the vacuities, and the more solid the mass. It may be also stated that very fine sand particles surround those of the

cement, and by separating them prevent complete cohesion, and produce a granular texture in the mass, whereas the object to be attained is to entirely surround and envelop every particle of sand with a durable coating of cement, the sand preventing contraction and desiccation.

Similarly, when a certain proportion of sand is used with the gravel in concrete, which should generally be the case, as if the interstices between the ballast or gravel are not filled with sand, the concrete or mixture will be much stronger and more porous than desired; the sand should not be fine, and additionally so, as pure sand has no coherence, and, therefore, unless each grain of sand is covered with a film of cement it will merely rest against the surface of the stone of the gravel, to which it has no adhesion.

If sand is not used, although there is always a little sand with shingle or gravel, the concrete is rough, has vacuities in it, and is consequently porous, and appears honeycombed, especially on the face, and the holes, as nearly as can be judged by the unaided eye, with concrete in the ordinary proportions, occupy from 5 to 12 per cent., of the cubic capacity, depending upon the size, form, and character of the gravel.

Fine sand will have more interstices than coarse sand, usually from 10 to 20 per cent.; although they vary considerably; in sea beach shingle they will usually be from 33 to 40 per cent. of the mass, and ordinary gravel will take about one-third of sand to fill its interstices.

Mr. Watt Sandemann, M. Inst. C.E., found by experi-

ment that the interstices of silicious sea sand, when not compressed, were about 40 per cent. of the volume of the sand. For fine or coarse, or a mixture of the two, the volume of the interstices did not vary much. When the sand was compressed with a rammer in water its volume could be reduced to the extent of $12\frac{1}{2}$ per cent. If, therefore, the volume of cement is equal to the interstices of the uncompressed sand, it will possess a sufficient surplus to ensure that there will be a film of cement around each particle of sand. Consequently, to produce concrete impermeable to water from Portland cement, coarse or fine silicious sand, and broken red sandstone to pass a 4 to 8 inches ring, the relative volumes of the two latter materials to 1 of Portland cement should not exceed $2\frac{1}{2}$ of sand and $5\frac{1}{2}$ of broken red sandstone, if such stone be used.

The practical result of a certain proportion of gravel and sand being used to a fixed quantity of Portland cement, is, if the interstices are filled, that the stones of the gravel become embedded in a matrix formed of the proportions of sand and cement specified.

With regard to the form of the particles of sand, the angular, small scale, or thin splinter form of the grains is better than the spherical, nodular, or rounded shape. In soft and quickly perishable sandstone, the grains are chiefly spherical, whereas in durable, compact, and strong sandstone they are sharp and angular. In the former there is considerably more foreign substance attached to the grains than in the latter, therefore, the latter are purer and better for engineering purposes; and the sharp grains will appear clean,

clear, and translucent, and not dull, murky, and opaque, as the rounded grains frequently do.

Pure sand has no coherence, neither is there any bond, overlapping, or wedging in rounded grains of sand; but in the angular, sharp, or pointed form there is a tendency to compactness, and friction is obviously greater.

Rounded grains of sand have generally been fashioned by mechanical attrition caused by weathering and water, and are more polished and smooth-faced than the sharp grains, and therefore do not afford so good and rough a surface for the cement to adhere to; nor is the ratio of their surface area to their cubical contents as large as in the pointed, angular, and fragmentary form, a not unimportant point as the strength of concrete is dependent upon the thorough incorporation of the particles. Within reasonable limits, the superficial area of a grain of sand, or a piece of stone, should be as large as possible as compared with its cubical contents, in order that the cement may have a considerable surface to which to adhere, therefore, neither should be nodular or round.

Preferably, the grains should be of uniform size, in order that equal strength and settlement may be obtained; the great stability of masses of material, angular in form, and uniform in size, is seen in breakwaters and roads; and if it is considered advisable to fill the interstitial spaces with a finer sand, the latter should be uniform in size.

The sand and stone should be as hard as possible, as cement has a greater adherence to a hard than to

a soft surface, and that obtained from the most durable rock should always be preferred, for if the stone on the face becomes disintegrated, the concrete will gradually decay, although the best cement may have been used.

Coarse clean sand, such as is found on a sea-beach, if washed clean, makes good mortar; and coarse sand, as previously named, makes a stronger mortar than fine sand; but if sufficient coarse sand cannot be obtained, the coarse and the fine sand should be thoroughly mixed and mingled, as stronger mortar is so made than with fine sand alone. Briefly stated, sand from the hardest rock is much better than from soft sandstone, and the largest, roughest, coarsest, and most fragmentary grained sands are the best for making concrete, or mortar; also large irregular shingle makes stronger concrete than that which is smaller and more worn.

It will generally be found that the size of the shingle and sand varies considerably along a coast, depending upon the facilities for attrition, but it frequently happens that the most exposed places have the largest, hardest, cleanest, and coarsest sand and shingle. During setting, cement concrete with angular particles of sand, or gravel, resists any tendency to slide in the work when temporarily and irregularly deposited, and any erosion of the cement between the particles, better than concrete made with rounded grains of sand and gravel, the latter, such as Thames ballast; and the friction between the surface of the gravel and sand and the cement being greater, separation of the cement

from the aggregates is not so readily effected during deposition. It also forms a more rugged surface for the attachment of layers, and the concrete settles more readily when rammed.

In breaking up Portland cement concrete it is found that with sand and gravel of angular shape, the mass is firmly joined together, and that there is but little appearance of a tendency to separate, but the reverse is the case with rounded stones. With the latter in the gravel, more sand, as a rule, is required than with angular stones, and, therefore, it is not so strong, and there is no wedging of the particles which conduces to strength.

The cleanness of the sand and stone or gravel is of very great importance, and any finely divided earthy matter upon it is injurious. Sand, when washed clean, has, by experiments, increased the strength of a Portland cement mortar about 10 to 15 per cent., as compared with the same sand used when unwashed and dirty.

The German standard sand is obtained by sifting clean quartz sand first through a sieve of 387 meshes per square inch, made of wire 0·0146 inch diameter, then through a sieve of 774 meshes per square inch, made of wire 0·0123 inch diameter. The sand which remains upon the finer sieve is that which is to be used for the tests.

The sand specified after many thousand experiments, under the direction of the French Minister of Public Works, was as follows. The standard sand is produced by crushing quartzite obtained from quarries near Cherbourg, and sifting it through sieves of 413 and 929

meshes per square inch. That which remains between these two sieves is washed and dried, and constitutes the standard sand.

The Austrian standard sand tests were as follows:—The sand must be clean washed crushed quartz, sifted through a sieve of 413 meshes per square inch, wire ·0086 inch in thickness, No. 32 B.W.G., then through a sieve of 929 meshes per square inch, wire ·0071 inch in thickness, No. 34 B.W.G. The residue on the latter sieve is the standard sand.

The recommendations of the Committee of the American Society of Civil Engineers, as to sand, were that:—The first sieve should have 400 meshes per square inch, the second 900 meshes per square inch. The sand to pass the 400 meshes sieve, and be caught on the 900 meshes sieve. The sand to be crushed quartz, as the committee found none other sand equal to it in sharpness, and uniform hardness of the particles. The sizes of the sieves are those that have been adopted previously by Mr. Grant and others.

The strength of concrete being dependent upon the adhesiveness of the cement to the sand and gravel, if the cement be very good, and the sand and gravel indifferent, the resulting concrete cannot be good.

In using large stones bedded in cement, great care should be taken that the stones do not touch, but are surrounded with cement. The mortar should be sufficient to separate all stones throughout and coat them with a film not less than one-eighth of an inch in thickness; therefore, when the volume of the interstices is found by water or any process in which the stones are not separated

at all points, about 10 per cent. should be added, and about 15 per cent. when a concrete is to be placed under water.

When no material for mixing with the cement can be obtained, clean rock can be crushed by stone-breaking machinery at a small cost, and it will make an excellent blending ingredient, if the rock is hard, and one usually better than natural sand; but all powder should be removed from the stone or sand when crushed, as experiments have proved that it reduces the strength of the concrete, and the stone and sand, after it is broken, should be washed.

In countries such as India, where very little sand is found of sufficient sharpness, brickdust is often used, and is preferred to fine sand. The particles of the brickdust should be as hard as possible.

Granite-chips, and rough, hard stone of a porous nature, such as hard sandstone, are excellent material to use when clean. The chief aim is to obtain durability and roughness of the surface so as to attract adhesion of the cement, and cause it to rest in order to attain thorough crystallisation. Broken bricks, however hard, should not be used in concrete exposed to sea-water as they become disintegrated, and durable stone should alone be employed.

Mr. W. Maclay ('Transactions of the American Society of Civil Engineers,' vol. vi.) made a great many experiments to ascertain the relative tensile strength of Portland cement mixed with very fine white sand, and sharp clean building sand containing a large proportion of coarse particles. Fine sand diminished the strength as

against coarse sand, with 1 of sand to 1 of Portland cement, 11 per cent.; and the reduction is greater if more sand is used.

Mr. Mountain, M. Inst. C.E., found by experiment at Sydney, N.S.W., that concrete made with crushed basalt gave greater resistance to crushing strain than when formed with river sand and gravel; also that the yellow sand of a hill near Sydney was quite unfit for mortar, but white drift sand was about equal in strength to coarse sand from the river Nepean. None, however, equalled that given by crushed sandstone.

There is considerable difference in a mortar made with coarse sand, and one with fine sand, for the sand governs the degree of porosity because of the different interstitial space between the particles. Mortars made with coarse sand will allow water to percolate through them more or less according to the proportion of Portland cement used. The effect of fine or very fine sand is to prevent percolation through a mass, but to admit water between the minute particles and pores, which are more numerous than in coarser sand, and hold it by capillary attraction; therefore, the result of using fine sand is to expose a greater surface to the water; but, as the water remains, and provided it is not renewed by *fresh* supplies of sea-water, which is the chief danger to guard against, as then the deleterious salts are being constantly renewed, it would appear that a mortar which retains the *same* water, or through which percolation is very slow, and prevents or hinders fresh supplies passing through it, is to be theoretically preferred to one which allows free percolation, and consequent continued fresh

chemical action, although exposing a less surface but larger interstices to the sea-water; but no concrete is safe in work under such conditions, and any percolation should not be allowed as sooner or later it will cause disintegration, either by decomposing or deteriorating the mass, or else by wave action producing air-compression or hydraulic pressure.

The gravel or ballast which in a given cubical measure requires the smaller quantity of sand to fill its interstices is to be preferred, provided the angularity and roughness of the particles are equal, inasmuch as less sand is required, and no increased quantity of cement, and, therefore, the stones are bedded in a stronger mortar having greater adhesive and other powers. For example: Assume a concrete to be 6 of gravel, having no sand attached to it, 2 of sand to 1 of Portland cement, which is 6 of stone set in a 2 to 1 cement mortar; but, if the 6 parts of stone require 3 of sand to fill the interstices, it is 6 of stone set in a 3 to 1 cement mortar.

Eight of stone and $2\frac{2}{3}$rds of sand to 1 of Portland cement is to be preferred to a mixture composed of 6 of stone and 3 of sand to 1 of Portland cement. It is assumed that the sand fills the interstices in the stone, and that thin face concrete is not under discussion. Reference to the tables of strengths will show the difference of the approximate strength of concrete composed as described.

It is no indication of the strength of a concrete to state 6 of gravel and sand to 1 of Portland cement, or 8 to 1, or 10 to 1, unless the quantity of sand

required in each case to fill the interstices is named, and equally proportioned. Assuming a 6 to 1 concrete required 2 of sand, and a 10 to 1 also 2 of sand, the relative strength of the concretes would not be inversely as about 6 to 10, but would nearly approach, for in each case the stone would be embedded in an identically composed mortar, although there would not be such a thorough incorporation in the 10 to 1 as in the 6 to 1 mixture. Hence the importance of having only enough sand to fill the interstices, see chapter, "Proportions of the Ingredients."

Mr. Kinipple, at Garvel docks, experimented upon the strength of Portland cement mortar mixed in the following proportions:—1 part of Portland cement to 1 part of sandstone, crushed in a Blake's crusher, and also mortar made of 1 part of Portland cement to 1 part of pit sand. The mortar mixed with the crushed sandstone was uniformly 55 per cent. stronger than that made with pit sand. The tests extended from seven days to three months. The average breaking weight on a $2\frac{1}{4}$ square inches area was 592 lbs. for the crushed sandstone, and 381 lbs. for the pit sand, or respectively 263 lbs. and 170 lbs. per square inch.

It is advisable, if the concrete will be placed in sea-water, that the shingle or aggregates should be obtained from the locality in which the works are situated, as they have already been subject to the chemical action of the salt water, and will therefore be less affected by it.

If very porous material is used instead of gravel or stone it absorbs a considerable quantity of cement, in

addition to being friable, and liable to disintegration, and it requires to be soaked with Portland cement before it is fit to be used as an aggregate; therefore it should not be employed if any other harder and stronger material is available, although it has shown, and may show, after thorough impregnation with cement, a higher compressive strength than non-absorbent substances. The cost of the absorption of the cement will very probably equal that of obtaining a hard and strong aggregate, and the latter should always be preferred.

All absorbent material used in making concrete should be saturated with water before the cement is applied, in order that the cement may not be deprived of the moisture necessary for setting.

In perfect concrete the cementing agent should be of the same strength as the aggregate under all strains in any direction and subject to like conditions, and to obtain this it is necessary that the attaching area of the particles forming the gravel and sand, enables the cement mortar they are embedded in to adhere to the stones with equal strength to that it possesses in bulk, and that the stones are regularly spaced, and of the same quantity, relative position, and cubical measurement in the whole mass. Such a condition is an impossibility in work; nevertheless, by taking into consideration the points named, if there is a choice of gravel or stones the better can be selected.

Some aggregates that do not make good concrete or mortar.

Loamy or argillaceous sand.

Very fine sand, such as "blown" sand.

Fine sand.

Road or ditch sand.

Impure sand or stone, i. e. that is covered with a scale, slime, or humus, or in a dirty damp condition.

Sand or stone impregnated with sewage or ammoniacal water.

Round or nodular grained stone or sand.

Stone or sand from soft sandstone rock.

Sand which is dull, murky, and opaque.

Stone or sand with a surface very smooth and polished.

Stone or sand that has lime scale or calcareous matter attached to it.

Pit sand, with a few exceptions.

Soft stone or sand with soft grains.

Shell sand, and broken shells.

Some aggregates that make good concrete or mortar.

Stone or sand from quartz rock. Granite chips.

Stone or sand from hard sandstone or other hard rock.

Split sea beach-stones if they have not very smooth surfaces.

All very hard angular and rough-faced stone or sand.

Sea beach shingle and sand, if not nodular and polished from mechanical attrition.

Sand from a river whose bed and watershed are rocky.

Note.—Preferably it should be taken along the course of the river, and not at its mouth.

Sand with large grains.

Note.—In the case of sand whose grains are equally coarse or rough use the larger grained sand.

Sand with coarse or rough grains.

Note.—In the case of sand with grains of equal size choose the coarser or rougher.

Sand which is clean, clear, and translucent.

The hardest stone or sand should be used.

The stone or sand should be angular and fragmentary in form.

The surface of the stone or sand should be rugged and coarse.

Stone broken from pieces of hard rock by a machine, the powder being removed.

Sand obtained from hard rock crushed by machinery, the dust being removed.

Sand or stone obtained from rock which is the most durable.

CHAPTER VII.

PROPORTIONS OF THE INGREDIENTS.

Quantity of cement and stone—Proportion of sand most important —Residue not to be considered Portland cement—General composition and the proportions of concrete.

WATERTIGHT concrete cannot be produced unless the cement, which is supposed to set perfectly watertight, entirely fills the interstices of the aggregates and encircles them, and it is therefore important to determine the minimum volume of cement requisite to fill them, and also to remember that sand retards the process of induration of the cement and weakens the mass, and if the best sand is used in too great quantity a concrete must be weak and porous, for the strength of a mortar varies according to the proportion of sand used, see chapter, "Tables of Strengths." A satisfactory concrete to be deposited in sea-water can only be obtained by the cement being properly proportioned to the sand, and the mortar so formed to the stone or gravel or aggregates, and in order to do so it is necessary to know the volume of the interstices of the aggregates to be cemented together to properly proportion them, and this can only be approximately ascertained until a test is made. A dense hydraulic

mortar has a greater capability of withstanding disintegration and desiccation than one not so compact.

If a volume of cement mortar be used slightly in excess of that of the interstices of the aggregate there will be sufficient, provided the materials are properly incorporated, to completely encircle and cover each particle of the aggregates, but no more sand should be used than will occupy the interstices in the gravel.

A simple method of ascertaining the quantity of cement required in concrete is as follows:—With the gravel or stone fill completely by shaking and ramming down a watertight box or measure, the cubical contents of which are known. Then add as much damp sand as possible, shaking it down amongst the gravel, the quantity of gravel, or stone, and sand being gauged before they are deposited. Then pour in as much water as the measure will contain; the quantity of water gives the net cubical contents of the cement required to coat the particles, which, however, should be increased by about 10 per cent. to allow for imperfect amalgamation, which cannot be so complete as with water, to allow for any defects in mixing in large quantities, and to ensure that all the interstices between the sand are filled with cement.

In a similar manner the volume of the interstices of the shingle or stone can be ascertained. Tightly fill a measure with the stone, and pour as much water into it as it will hold; the volume of water required is the cubical contents of the interstices, which should be filled with sand.

As there is a difference in the proportions if they

are measured or weighed, it should be stated in what manner the proportions are to be determined. In this chapter, unless otherwise described, measurement is referred to. The difference is not inconsiderable, and varies according to the relative weight of the materials per fixed volume. It has been suggested that, in order to detect any error in the proportioning, a measurement by volume should be checked by one by weight, so as to ensure uniform denseness, inequality in which might be caused by slowly or quickly filling a measure, or by doing so from different heights.

In relation to strength it has been proved that the strongest concretes are the cheapest, and the tensile strength of concrete made of Portland cement is, approximately, nearly in proportion to the quantity of cement in it, the aggregates being of a similar nature.

Some experiments made by Dr. Michaëlis showed that Portland cement and sand (i. e. a cement mortar) do not become disintegrated when properly mixed and incorporated. Neat Portland cement, on the contrary, has a tendency to contract, and consequently fissure, and the effect of such action is the cause of the disintegration of neat or very rich cement mortars exposed to the atmosphere, but by mixing the neat Portland cement with sand these deleterious results are prevented; therefore neat Portland cement is not well adapted for general constructive purposes, but when it is properly mixed with not less than 1 of sand it is not so affected.

Neat Portland cement which has been immersed for years and is then exposed to the air for 2 or 3 months,

experiments have shown loses strength very considerably. The reason is believed to be that by continued separation of its water, the mass becomes denser, and although the separate particles become harder, capillary fissures which affect the cohesion are produced by contraction, and desiccation commences. If the atmosphere was sufficiently humid so that the cement contains the water of hydration the effect is very much lessened.

In stating the proportions of the different ingredients in concrete, the correct way of naming them is to compare the cubical contents of the cement with those of the other materials. Any sand that may be used, if in such quantity as only to fill the interstices of the gravel, cannot be taken as adding to the quantity of the aggregates. Assuming a mixture to be 6 of gravel, 2 of sand, and 1 of cement, the proportion of the aggregates or other ingredients to the cement is 6 to 1, and not $6 + 2 = 8$ to 1. The concrete is 6 of gravel set in a mortar of 2 of sand to 1 of Portland cement.

The sand should fill the interstices in the shingle or stone, and should always be regulated with care, as the strength of concrete greatly depends upon the proportion of the sand and cement mixture in which the stone or shingle is set or embedded; hence the ratio of sand to stone or shingle is of great importance.

Respecting the proportions to be used between the cement and the other ingredients, the situation and purpose of the work, the degree of cleanness, sharpness, durability, and angularity of the sand and gravel,

or ballast, and the other questions previously and hereafter mentioned, must be considered.

The system of facing concrete can be adopted in many cases with advantage and economy, inasmuch as a comparatively weak concrete can be frequently used, provided it is hermetically coated with a face of impervious concrete. Future practice may incline in the direction of forming the hearting and all unexposed masses of concrete of a large proportion of angular stone of small size, such as will pass through a ring of about 3 inches in diameter in any direction, say 9 to 12 of stone to 1 of cement, without any mixture of sand, except that which adheres naturally to the stone, the rock or stone concrete necessarily being of a porous character, although possessing great strength, as the stones are encircled by neat cement and not cement and sand; hence the necessity of preventing the percolation of water into the mass by having a thick facing of impervious and durable material. A computation, however, should be made of the cost of increasing the richness of the mass and having no face concrete. In thin work a facing may not be economical, but in such structures as breakwaters, dock walls, and similarly exposed structures, it is most valuable and necessary. If no impervious face-concrete is adopted, sand should be used sufficient to fill the interstices in the gravel or stone, and the cement should completely fill those in the sand.

About the weakest cement mortar that the gravel or stones are embedded in is 4 of sand to 1 of Portland cement; but this is a feeble mixture, and now, it may

be said, not used, and 2 parts of sand to 1 of Portland cement should not be exceeded for heavily strained work, and it may be found that with a proportion of sand to cement greater than 2 to 1 the mortar may lose more in strength than the cost of the additional cement to make it a 1 of Portland cement to 2 of sand mixture, and this is almost the weakest matrix that should be adopted in marine work or any of importance. A richer mortar should be employed for exposed work in deep water, and 1 of Portland cement to 1½ of sand be considered about the minimum mixture when well mixed with sufficient water to admit of perfect crystallisation, as density is necessary in order to obtain durability, for a pervious mortar will allow cement to be washed out of it, and 2 to 1 it is not advisable to exceed, although a 2½ to 1 mortar has been shown to be the most economical proportion for impermeable mortars, but, for other reasons, 2 to 1 is the weakest it is expedient to use.

Various experiments have proved that a 1 of Portland cement to 1½ of sand mortar will cause a concrete to be sufficiently impervious to resist such water pressures as 30 lbs. per square inch, and that, as might be expected, the resistance to percolation decreases rapidly as more sand is added. The richness of a mortar should be regulated according to the head of water and exposure to wave-action and abrasion of the face by shingle during storms, which may make vulnerable places. An impervious proportion for concrete for sea work, properly mixed and deposited, is 1 of Portland cement to 1½ of sand to 3 or 4 of stone. Large stones being

inserted at regular intervals from a few feet below low water, or wave action, to bind the mass together. Water with a head of 27 feet will flow through a 7 to 1 concrete.

If Portland cement concrete is to be used for facing copings and steps, it should have no sand mixed with the granite, quartz, or rock chippings, which make the best aggregate for this purpose, in order to render its surface moderately rough. Small pebbles should be used for concrete paving and no sand; on the other hand, for watertanks, reservoirs, aqueducts, pipes, and sewers, the concrete must be impervious to water, and if the concrete is not faced, preferably no stone or gravel should be used, but the mixture should be cement and sand, and although fine sand makes bad mortar it lessens percolation of water through the mixture. If gravel is used for these particular works, the cubical contents of the cement and the sand should be not less than 50 per cent. of the gravel or stone for the concrete to be impervious.

In most specifications it is named that the Portland cement, leaving not more than a stated residue, shall pass through a sieve having a certain number of wires per lineal or square inch. This residue varies from about 33 per cent. to 5 per cent. It is mentioned in the Chapter on "Fineness and Weight," that the coarse particles left in their imperfectly ground state on the sieve after sifting are no better than sand, and some prefer sand to this residue. As the residue is generally used in the work, it follows that, whatever proportion is specified of gravel and sand to Portland

cement, practically the resultant proportion is increased, and therefore the concrete is weakened. For example, assume 10 to 1 as the proportion of gravel and sand to Portland cement and the residue as not to exceed 20 per cent.; provided the residue is used, which is almost invariably the custom, the proportion in the work of the concrete is not 10 to 1, but

$$10 \text{ to } (1 - \cdot 20) = \cdot 80 \text{ of Portland cement,}$$

or a $12\frac{1}{2}$ to 1 concrete—a considerable difference, amounting roundly to a decrease in the tensile strength of about 25 per cent., and in the compressive strength of about 35 per cent. Hence the importance of a small residue and extreme fineness in Portland cement, and attention being directed to the actual and not the specified proportion of the aggregates.

The required proportions of the ingredients in Portland cement concrete are principally governed by the quality and character of the materials, the nature of the specification, and the purpose to which the concrete is to be applied. In sheltered works and in situations where no marked fluctuations of pressure are likely to occur, the ratio of the aggregates to the cement may be increased, but in all cases the question of cost, the risk, the exposure, and the strain must be taken into consideration, and also the durability of the stones forming the gravel.

In certain works the faces and the space from the foundations to low-water mark might be of strong, impervious, and durable concrete, and the hearting above low water, and between the faces of the work, of a weaker mixture. Whether it is better to have one

proportion throughout, or the faces and base to about low-water line of stronger concrete, is open to question, and no general rule can be prescribed; nor is it of much value to compare the cost of concretes in different works unless the conditions are known and are practically similar, as it depends largely upon the material and facilities at command. For this reason, no estimates of the cost of producing any mixture are given herein, because they might mislead, for the locality, the expense of transit, first cost of materials, labour, water, nature of work, mixing, and method of deposition may vary, and much influence the cost; and to attempt to fix a price for concrete for even the different classes of work such as for marine purposes, breakwaters, harbours and moles, groynes, dock, wharf, and retaining walls, isolated abutments and wingwalls of bridges, buildings, archwork, and all the various uses to which Portland cement concrete can be applied, could only result in an approximate estimate, for local circumstances may cause considerable variation in price, quite independently of that of the Portland cement.

It may be important to have water-tight concrete; if so, it should be remembered that a small hydrostatic head will cause water to percolate through such a mixture as 12 or 10 to 1, and that until a 6 or 5 to 1 Portland cement concrete is used it will not resist a considerable head of still water, and 4 to 1, or 3 to 1, in exposed marine work in order to prevent percolation is frequently as weak a mixture as desirable, as for a graving dock; but, by attention in the proportioning of the aggregates, incorporation, mixing, and deposition,

the porosity of weak concretes can be considerably lessened.

In important works nominally 12 to 1 is the limit now reached for sheltered places and from 4 to 8 to 1 is the most general proportion for exposed and variably strained walls. It is not prudent, if the concrete will be subject to severe strain and wave-action on an exposed coast, that the proportion of 6 of gravel or stone and sand to 1 of Portland cement should be exceeded. 9 to 1 has been found to be too weak a mixture for exposed sea work, but 6 to 1 succeeded. The proportion should not be more than 6 to 7 to 1 for sea work deposited *in sitû* in comparatively sheltered situations, nor more than 8 to 10 to 1 for blockwork similarly placed, all being securely covered with thick durable face concrete, see Chapters XV.–XVIII. In depositing freshly mixed concrete *in sitû* it may be necessary to use a stronger concrete in the stormy than in the calm season.

There is no doubt that it is better to have the hearting of a pier 8 to 1, and a thick face and bottom and top cap of 4 to 1, the surface being properly faced, than all the mass of a 7 to 1 mixture, although the cost may be the same.

It should be remembered that it by no means follows that one concrete, although equally proportioned to another, is of equal strength, as will be patent from these notes, for the quality and nature of the ingredients may be different.

Such a ratio as 12 to 1 should only be used when all the materials are of the best kind and properly tested,

proportioned, mixed, and carefully and leisurely deposited; and at present this ratio should not be exceeded, particularly remembering that with a 20 per cent. residue of the cement after sifting being allowed the concrete is only about a 15 to 1 mixture in the work. Twenty years ago 6 to 1 was considered the prudent limit; 6 of Thames ballast to 1 of Portland cement was the frequent London practice. Then the tendency was to err on the side of great strength; now, although Portland cement can be obtained of good and uniform quality, and has been employed with the proportions between the aggregates and the Portland cement more than double the limit usually adopted about twenty-five years ago, a general acceptance and use of so great a ratio without careful and expert supervision is to be deprecated. In this country at that period Portland cement concrete was generally only used for foundations, backing, and secondary works. For such important structures as dock and sea walls, breakwaters, bridges, &c., and other works of the first order, it was more feared than trusted, except by the few who knew its intrinsic value.

It should not be forgotten, however, that no authentic practical test on a large or a small scale exists of the behaviour of a 12 to 1 Portland cement concrete after fifty years' exposure and strain, although there is some reason to expect it will be satisfactory, and that it will withstand the assaults of time, the disintegrating effects of the atmosphere, and the vicissitudes of climate, provided it is not exposed to wave-action, and the face is protected and maintained. Portland cement,

however, being so cheap, it is not true economy to have little cement in the mixture and to starve the concrete.

For exceptional work, where the concrete will probably be exposed to uprising water, or if it has to be passed through a great depth of water, it should be richer than for ordinary purposes.

With regard to the comparative value of Portland cement and lime concrete, in many cases there is no doubt that instead of blue lias lime concrete, Portland cement concrete with a much greater admixture of sand and gravel could be used at the same or even less cost with much increased strength, expedition, and durability. On this question see chapter "Cement and Lime Mortars."

Some comparative experiments by Mr. Bernays at Chatham Dockyard showed that concrete made of 1 part of blue lias lime to 6 parts of river ballast was not so good or reliable as concrete made of 1 part of Portland cement to 12 parts of ballast, and that blue lias lime concrete did not always set well under water.

CHAPTER VIII.

MIXING CONCRETE.

Hand and machine mixing—Proportioning—Quantity and temperature of water, fresh and salt water, damping the aggregates, &c.

WITH regard to concrete-mixing machines, the great point is to see that they thoroughly incorporate the ingredients, and that the materials are not placed in one part of the machine to be ejected at the other before they are completely mingled. However, hand mixing properly supervised by experienced men, according to instructions, and performed by those familiar with the work, is preferred by some to machine-mixed concrete, but there is considerable uncertainty with regard to it being equally mixed, and machine-made concrete, if care is taken not to disturb it when mixed, will generally be found to be superior to hand mixed. The reasons why some prefer hand-mixing are, it is found that some mixers do the simple mixing admirably, and usually more evenly and thoroughly than if done by manual operation; but the conveyance of the concrete from the machine to the site of the works is not so readily effected, the difficulty, and the thing to be guarded against, being the separation of the aggregates, i. e. the gravel and sand, from the matrix or cement. In fact, the concrete which has been properly

made in the mixer becomes, as it were, unmixed in its delivery to the place of deposition. When delivered from the machine to a platform it has to be put into barrows and deposited, and as the mixing machine cannot be easily moved, and the concrete has two deliveries instead of one, which latter is the case when it is mixed on a platform on the spot, mixers are then at a disadvantage, and the particles forming the concrete may become separated, and the concrete not a homogeneous mass, and in the work consist of horizontal layers or laminations, possessing different degrees of strength; therefore a comparatively fine concrete is more suitable for machine mixing, and a 4 inches ring has been considered a desirable limit of size for the aggregates to pass through, and an 8 inches ring the maximum.

If very large quantities of concrete are required to be mixed in a short space of time, the employment of mixing and delivering machines is almost a necessity. On large and confined works they can be so arranged as to deliver the concrete without materially disturbing it after the operation of mixing has ceased. At Newhaven Breakwater a portable continuous mixing machine, which thoroughly mixed the materials first dry and then wet, running on ordinary rails, designed by Messrs. Carey and Latham, was used, and fulfilled this condition. It could deliver 70 cubic yards of concrete per hour into the timber framing, and a lineal yard per day of the upper portion of the breakwater was thereby completed. The fixed continuous machine automatically measured, mixed, and delivered 100 tons

of concrete in twenty minutes. At Newhaven Harbour Works it was found that the labour on a 100 ton bag of concrete cost 1*l.* 15*s.* by this mixing machine, and 5*l.* 5*s.* by piecework hand-mixing. The cost of mixing the raw materials by hand was about 1*s.* 2½*d.* per cubic yard, but only 5½*d.* by the portable machine. On the Manchester Ship Canal Works, 12 of the Carey and Latham portable machine mixers have been used with entire success.

The thorough incorporation and mingling of the ingredients should be effected without any pulverisation of the particles, and is of the greatest importance, for imperfect preparation and mixing of the materials causes a want of homogeneousness, and then the hydration and setting of the concrete will not be uniform in time or manner.

Mixing machines constructed upon the principle of a bladed screw-shaft revolving in a trough, with a slight fall towards the delivery end, to which the materials are moved as the blades revolve, are greatly to be preferred for Portland cement and lime concrete to the pan and roller system, which deteriorates the mixture, inasmuch as it grinds and pulverises the aggregates, thereby reducing the sharpness, coarseness, and angularity of the gravel and sand. The system of mixing by means of a bladed screw-shaft in a trough is also much more expeditious than the pan and roller method of incorporating the materials, which should be generally abandoned for mixing Portland cement mortar.

Vertical mixing machines are principally used when small quantities of concrete are required as in buildings,

but the horizontal machines are to be preferred for engineering works, and have to be employed when concrete has to be mixed in large quantities.

An efficient mixing machine is made of an open trough of wrought iron, 6 to 10 feet in length and from 3 to 4 feet in width. The lower half is semicircular, and the top half slightly splayed outwards. A shaft from 3 to 4 inches square passes through the centre of the trough. On the shaft are fixed wrought-iron blades, about 14 or 15 inches apart throughout, the first blade being fixed at about 7 inches from the end of the trough. The blades project in different directions alternately, and are arranged so as to screw the concrete forward as the shaft revolves. The trough has a slight fall towards the place of delivery. At one end is a wheel, round which belting can be used for communicating motion. The blades are made of a length so as nearly to touch the sides of the trough. This trough can be fixed anywhere on a couple of trestles. Its cost, as stated by Mr. B. B. Stoney, is about 35*l.*

This mixer is intended for ground lime or cement, and not for lump lime, for which latter the pan and roller system is useful to crush the lumps of lime. It is claimed that 8 to 10 cubic yards of concrete or mortar per hour can be made with this mixer, with 30 revolutions of the shaft per minute when driven by a 3 horse-power engine, and that it makes as much mortar as twelve ordinary pan mills.

Another approved machine mixer is that of Mr. Messent.

The experiments of Mr. Grant showed that neat Portland cement is weakened by being mixed in a mortar mill. The cement weighed 110½ lbs. per bushel, and was in one case mixed by hand, in the other by a mortar mill, 30 minutes. At the end of one month that which was ground in a mill had less than 75 per cent. of the strength of that which was mixed by hand. One hundred and ninety experiments were made to ascertain this. The maximum strength of that mixed by hand was attained at five months, and that ground in a mortar mill at one month, the greatest strength of the former being nearly double that of the latter. The strength of that which was mixed by hand was maintained, while that which was ground in a mortar mill declined from the maximum in each case to the end of the experiments; the result being considered due partly to the process of crystallisation or setting having been interrupted by the continued agitation, and partly to the destruction by attrition of the angular form of the particles. On the other hand, it has been stated that this decrease in strength of mill-mixed cement mortar as compared with hand-mixed is caused by the materials having been mixed in the mill for an excessive time, 30 minutes. If 6 or 7 minutes were tried it was believed the results would be reversed, but this is an expression of opinion, and one which has yet to be proved by experiment

Mr. B. B. Stoney's method of mixing the dry materials of concrete or mortar before delivery to the machine was as follows:—On a large tray the ballast or sand was firstly laid. Supposing the sides of the

tray to be 4 feet in height, and the proportions required to be 6 to 1, by measure, planks 8 inches in height are fixed upon the top of the 4 feet height, and cement is deposited for that depth. Men then shovel the material into the mixer, pushing their shovels along the tray, which is open at both ends; thus the cement sheds itself uniformly down the slope of the gravel and becomes mixed with it to a certain degree before reaching the machine. No hand-mixing is done; the materials after being tossed over are thoroughly incorporated by the first three or four blades of the mixing machine previously described. They then pass under the water-rose fixed at about one-third of the length of the trough from the upper end and to the delivery end; the mixture of gravel, cement, and water being perfected, and the mortar or concrete issues uniform in colour and homogeneous in quality.

When the proportions of the different ingredients are fixed, if the preceding tray and plank system is not adopted boxes should be made of different sizes corresponding with the proportions of the cement and the aggregates. The cement-box should be made to hold the quantity of cement contained in a bag or barrel, and the boxes for the shingle, ballast, gravel, or sand should bear the proportion desired in the mixture, as trouble is saved, the operation of mixing is simplified, and it is obvious it is a ready check.

Respecting the relative merits of the tray and the box system of proportioning the ingredients. Both have their advantages, and are effectual if due care is exercised. Provided the boxes are filled and

deposited ready for mixing in their regular rotation, it is perhaps easier to apportion the material in its correct quantity in a box than over a surface such as a tray affords, but if the tray is rightly covered there is not the chance of unequal dry proportioning which there may be should a box of cement be omitted; hence all depends upon the supervision. For feeding a machine mixer probably the advantage rests with the tray and plank arrangement.

The dry materials should never be lowered through the water between panels or covering, but should always be first mixed with water on land; neither should a box be filled with the dry materials and the water be added to them in the box, as the concrete in both cases will then be full of cavities, as the gravel and sand will settle about 15 to 25 per cent. in volume on water being added, depending upon the size and character of the ingredients. If dry Portland cement be dropped into water it is found that each particle becomes separately crystallised and without any cohesion to others, therefore every precaution should be taken that the particles do not become separately set, but all cohere in setting. For this reason the water used in mixing should be gently added. It may be here stated that mineral waters and oil only damage Portland cement mortars or concretes when they can penetrate the mass.

If there is little room for mixing on the site, skips on waggons can be delivered containing the dry materials, the skips being divided into partitions, and each division containing the required quantity of Portland

cement, stone, gravel, or sand, which can then be mixed in a dry and in a wet state on the site, and be immediately deposited.

Respecting mixing the materials by hand, they should be first turned over not less than three times in a dry state, and unless they are so mixed and intermingled concrete is not likely to be solid, of equal character, or durable, and then be mixed three or four times in a wet state, thus thoroughly mingling the ingredients; and the required quantity of water should be very gently added from a spout with a fine rose-end attached, so as to prevent any cement being washed away, and to uniformly wet the whole mass. If it is decided to damp the gravel, sand, or stone, of course the mixture cannot be turned over in a completely dry state, which does not often happen in this country. In England or temperate climates there may not be occasion to damp the aggregates before mixing with the matrix, but it should not be forgotten that they absorb moisture, and may rob the cement of its proper share if an allowance is not made.

Mixing by hand is sometimes effected by first mixing the Portland cement and sand three times or so in a dry state, then a small quantity is mixed with water, and the mortar is spread to a certain height on a wooden platform, a layer of stones or gravel is spread upon it, having a thickness proportional to the mortar and that required in the concrete, and is so alternately continued as desired, the mass is then turned over several times by shovelling until considered properly mixed. This method, doubtless, very well mixes the

materials, but care must be taken that the mortar is simultaneously gauged, or a portion may be partly set before turning over, and part quite freshly mixed.

None of the aggregates forming the concrete should be allowed before deposition to touch bare ground, unless previously cleaned, but should be mixed on a plank bed, and the cement be taken from the store direct to the mixing platform, or mixer; and no Portland cement or concrete after being mixed should be softened or re-mixed with an addition of water to enable it to be deposited in work, as setting operations are most seriously affected by such action, and the concrete is also more rapidly decomposed by sea-water.

With respect to the water required in mixing in the test-room, only the amount necessary for mixing need be used, and consistent results in testing can only be obtained by adopting identical proportions of cement and water; but in mixing on the site in order to provide against evaporation, filtration, absorption by brickwork or stonework that the concrete may bear upon, an excess of water above that required in the test-room is generally used to facilitate the filling of trenches and vacuities, to prevent cracks in the concrete, and also to counteract the action of the sun and wind, particularly if the work is above the natural ground level. An excess of water, however, in concrete mixing is an error, for then the water affects too much the grains of the cement, which should be brought to a moderately gelatinous state sufficiently liquid to encircle the particles of sand, and for the resulting mortar to surround the aggregates; separates the particles of cement

and sand, delays the hardening and drying of the cement, and makes it more porous than it otherwise would be. Consequent upon a slight excess of water having been found in gauging test briquettes to reduce their strength, it seems from recent experiments the tendency has been to frequently use too little water rather than too much in mixing Portland cement concrete. Formerly gauging to a merely gelatinous or pasty condition was the most generally approved, but during the last few years the proportion of water has been in many cases increased, and with apparent advantage for concrete in mass. Some reasons for using more water in concrete than in test briquettes have been mentioned. The state of the weather, and whether concrete is to be deposited under water, are other points to be considered; the chief aim should be to have no excess and no insufficiency, and the latter is especially to be avoided, because hydraulic cements depend for their property of hardening under water on the increase of density consequent upon the chemical reactions due to the absorption of water and carbonic acid, and therefore it cannot be properly effected without sufficient water, in fact, no chemical action can take place without water. When insufficient water is used in mixing there will be air spaces in the mass, the concrete will be porous, and then the unset portion may be washed out, and the lime in it be dissolved, and in addition it cannot set properly or become crystallised, for the proper setting of the cement can only be obtained by the necessary water being mixed to ensure the required chemical combination of the lime with the

silica, &c., &c. The point to attain is to supply sufficient water to ensure thorough crystallisation, and yet not to wash away some particles and prevent the setting of others, for when sufficient is provided to effect the crystallisation or solidification of the mass, any more weakens the cement by washing away the soluble silicates contained in it, and as any such excess of water, if it does not drain or leak away, will evaporate in time, apertures will be caused, however small, and the mixture be porous and weak, as all the particles will not be entirely encircled with and joined together by the cement.

Mixing the mortar or concrete with a sufficiency of water is not, however, all that is required, but to retain sufficient water in the mass for it to produce its full hydraulic properties, therefore the concrete in dry situations or where there is decided evaporation should be protected until it has had full time to completely set, and to ensure this the mass requires to be in a gelatinous condition. The danger of insufficient water is not only that the required chemical action does not fully take place, but moisture, when the concrete is deposited, may afterwards percolate and chemical changes occur which will cause dilaceration and perhaps disintegration of the mass. For this reason compact impervious concrete cannot be made without an amply sufficient quantity of water, as *porous* concrete is especially unreliable and weak in marine works, unless impermeably faced, and undesirable in any other. A slight diminution in strength is of no importance as compared with an insufficient supply of water for setting

and hardening. In some experiments by Mr. Bamber it was found that when the full quantity of water was used $12\frac{1}{2}$ per cent. more of the mass could be easily put into a box than when only half the quantity of water was used, the space in the insufficiently watered concrete being occupied by air necessarily made the concrete porous.

It is advisable to ascertain the quantity of water required to bring a given measure of cement to a proper and equal consistency, and it is important to mix concrete or mortar to the same stiffness to attain equal results, to make it set evenly, and be of the same character. The want of homogeneity and uniformity in strength and durability, and in the colour and appearance of a concrete wall, is due, in great measure, to the proportions not being identical, and to a difference in the amount of water used in mixing; but it is difficult to make a concrete wall without a face-coating of exactly uniform colour and appearance.

In hand-mixing, labourers frequently add an excess of water to facilitate operations; this should not be allowed, the least proportion necessary for easy manipulation should be ascertained and be always used; or the water is added in irregular quantities, and unless carefully supervised the ingredients may not be properly incorporated.

It is important to reduce the water to a correct minimum and not to vary the correct quantity required to make the cement into a thin paste, and enable it to properly set and harden under all circumstances. New, freshly ground cement absorbs more water than

that not so recently manufactured, and fine sifted cement more than the same when unsifted, and quick-setting cement more than slow, about 10 per cent. additional. In order that a Portland cement having a high percentage of lime may become properly indurated, it should have more water and more time for absorption than one containing less lime. Some aggregates are non-absorbent, others are absorbent, therefore no fixed rule can be given for the correct proportion until a test has been made, although it may be approximately known. While shingle or stone of a dense character would absorb very little water, porous stone would take up a considerable quantity. The amount of water required to bring the cement to a thin paste may vary with the state of the weather; in a hot and dry atmosphere the necessary quantity of water may be as much as 10 per cent. more than if the weather was damp and humid. If concrete has to be placed upon dry, porous soil, more water should be used than when it is deposited upon a damp, retentive stratum. The quantity of water required may briefly be said to be that which will chemically combine with the cement, and as the latter varies in composition, it will also vary.

At the Portsmouth Dockyard extension works, Mr. Colson made some experiments to ascertain the relative tensile strength of concrete when mixed with a maximum and minimum of water. The results briefly summarised were in the case of a mixture of 2 of broken brick to 1 of sand to 0·33 of Portland cement, tested after 6 months, as 1·13 to 1 in favour of the minimum of water, and similarly with 2 of Portland stone

instead of broken brick. With a mixture of 2 of harbour shingle to 1 of sand and 0·33 of Portland cement, 1·33 to 1 in favour of the minimum of water for mixing. These are in accordance with Mr. Grant's and other reliable experiments. He also found that the best proportion of water to cement, both as regards convenience of mixing and results, to bring it to a paste or workable condition, was 1 of water to 3 of cement by measure, or 1 to 3½ by weight. A slight variation of these proportions may be required, depending upon the age and fineness of the cement.

Mr. Grant has shown by experiments with test briquettes that neat Portland cement mixed with 25 per cent. of water by weight had 22 per cent. less tensile strength than that mixed with 19 per cent.; but the quantity of water required for proper mixing varies according to the cement, the extreme range being from 16 per cent. in the test-room to 28 per cent. on the work when mixed neat, and the usual quantity from 18 to 22½ per cent. by weight. For a mixture of 1 of Portland cement to 1 of sand, about 15 to 16 per cent.; and for a mixture of 1 of Portland cement to 2 of sand about 12 to 14 per cent. by weight; and about 10 to 12 per cent. (12 per cent. was the Austrian standard rule), by weight of the cement and sand is the quantity of water for mixing test briquettes, proportions 1 of Portland cement to 3 of sand. Fine sand usually requires about 15 per cent. more water than coarse sand.

Mr. Carey, at the Newhaven Breakwater and Harbour works, found that 21 to 23 gallons of water per cubic

yard of concrete, i. e. good, clean shingle or stone, clean sharp sand, and cement, gave the best results. This would be from $\frac{1}{7}$th to $\frac{1}{8}$th, or 14 to 12 per cent. of the volume of the concrete. The concrete consisted of 5 parts shingle, 2 parts of sand, and 1 of Portland cement.

In referring to the quantity of water to be used it should be clearly stated whether it is proportional to the cubic foot of concrete, that is, the stone, sand, and cement; or to the cubic foot of cement only, as, at first sight, it would appear that there was considerable diversity of advice as to the approximately correct quantity, whereas there is not much difference, and it is accounted for by special circumstances and the nature of the aggregates. The proportion just mentioned, taking the Portland cement only, would equal about 4 gallons, or 40 lbs. weight, per cubic foot of the Portland cement only, thus, if 4 cubic feet of Portland cement were used in a cubic yard of concrete, the quantity of water should be about 16 gallons, or 160 lbs. by weight. In the case of mixing *neat* Portland cement, the proportions found by the numerous experiments of Mr. Grant can be adopted. It is sometimes considered better to proportion the water by weight, and not volume, as being the most reliable method. Mr. Bamber made some experiments with concrete blocks placed in the sea, and found that when 4 gallons of water were used to a cubic foot of cement the concrete was perfectly sound and hard, but when 2 gallons only were used it was soft, rotten, and wet under the same conditions, and that when 3·13 gallons were used, the

concrete was satisfactory, but with 2·35 gallons it was unsound, and with only 1·56 gallons it became disintegrated. In order to make durable and sound concrete, it may be generally considered that about 4 gallons, or 40 lbs. by weight, for every cubic foot, which equals 0·781 bushel, of the Portland cement used in a cubic yard of concrete, subject to additions for the reasons mentioned in this chapter, so that the quantity supplied for the cement may be entirely reserved for it, is necessary. M. Feret in a series of experiments, which confirm others, found that the best quantity of water to use varies according to the cement and aggregates, and that if the quantity of water used in mixing was progressively diminished, the permeability of the mortars or concrete produced increased very rapidly. In submitting, however, mortars or concretes mixed with different proportions of water to percolation it was found that the very different initial permeabilities soon approached uniformity, owing to the gradual closing of the pores; so that the percolation of water caused the partial disappearance of differences due to different proportions of water in mixing; also that a mortar or concrete mixed with too little water must be less compact and have more interstices than a very plastic one, and therefore must be subject to the decomposing agencies of sea water.

In the specification drafted after extensive trials ordered by the then French Minister of Public Works, the quantity of water is ascertained by a preliminary experiment, and the four following tests are given to serve as an indication whether the proportion of water

added is correct: 1. The consistence of the mortar should not change if it be gauged for an additional period of three minutes after the initial five minutes. 2. A small quantity of the mortar dropped from the trowel upon a marble slab from a height of about 1·64 foot, should leave the trowel clean, and retain its form approximately without cracking. 3. A small quantity of the mortar worked gently in the hands should be easily moulded into a ball, on the surface of which water should appear. When this ball is dropped from a height of 1·64 foot, it should retain a rounded shape without cracking. 4. If a slightly smaller quantity of water be used, the mortar should be crumbly and crack when dropped upon the slab. On the other hand, the addition of a further quantity of water, 1 or 2 per cent. of the weight of the cement, would soften the mortar, rendering it more adhesive, and preventing it from retaining its form when allowed to fall upon the slab. It is recommended in experimenting to commence with a rather smaller quantity of water than may be ultimately required, and then to make fresh mixings with a slight additional quantity of water.

It may be well to state that these tests are made with *neat* Portland cement and water.

In the German standard rules, in making briquettes for the tensile test, 0·55 lb. of cement is mixed with 1·65 lb. of standard sand, and 0·22 lb. fresh water, the whole mass being well mixed for five minutes. The mortar is beaten into the moulds for one minute with a spatula weighing about 0·55 lb., until water begins to rise. In making the neat tests, 2·204 lbs. of the cement

is mixed with 0·44 lb. of water; but with very finely ground or quick-setting cements, the amount of water may be increased.

Care should be taken that the concrete when finally deposited in the work has not less than the same quantity of water as it required for the test briquettes, and that it is sufficiently wet to be impressed with the hand, but not much softer, in order that no cement may be carried away. A simple approximate test of the proper quantity of water having been used in mixing is by punning the concrete; if the correct quantity of water has been used, no water will be spurted up on its being punned, but a slight surface exudation will be noticed.

The purity of the water used in mixing is of much importance, as any silt, mud, or sediment in it spoils the concrete. In situations where ammonia is present, as in sewers, fresh water should be used for mixing, because of chemical action being produced by the ammonia and the salts in the sea-water. Portland cement mixed with even slightly dirty water takes longer to set and is weakened. Sea-water was generally considered as good as fresh for mixing purposes, in fact, if the concrete was to be deposited in salt water, some preferred that sea-water should be used in mixing and not fresh; and careful tests showed that Portland cement was even better when mixed with sea instead of fresh water under certain circumstances; but the following experiments do not confirm this, for Mr. Faija deduced from 360 experiments, in which all the details of the tests were identical, and in testing a cement weighing 112 lbs. per bushel, and which left a residue

of 25 per cent. on a No. 70 sieve, and in gauging which 17·24 of water, whether fresh or salt, was used; that the salts in sea-water deleteriously affect cement mixed with sea-water, and afterwards immersed in either sea, or fresh water; but act beneficially when the cement is only exposed to the action of the air, and that the same salts have a decidedly favourable effect when acting upon cement mixed with fresh water; and concluded, therefore, that for marine purposes the portions of the work which are above high water should be gauged with sea water, and those parts below high-water level should be mixed with fresh water.

However, the effects of mixing Portland cement, and cement and sand, with sea-water appear to be different for neat cement at first shows greater strength when mixed with sea-water, but declines after a few months. Cement mortar, i. e. Portland cement and sand, does not decline in strength, and it increases, especially if the cement is finely ground, the full strength being attained after about one year.

It is well to remember that the tests as to the effect of mixing Portland cement with sea-water have been made with ordinary sea-water taken on the British coast, the solid constituents of which are said to be about 3½ per cent. by weight in 100 parts, and that the salts, some nine in number, are various, and that common salt is only one of this number, and that the quantity of saline matter in the sea varies considerably, the density increasing with the amount of salt; the greater the evaporating power the salter the sea, and that the water of cold climates is not so rich in salts as

the warm seas. It is possible the action of very dense, i. e. very salt sea-water, may affect deleteriously the strength of Portland cement, and it may reasonably be thought that as the quantities of the salts increase, their effect upon the cement will be accentuated. The range of the amount of salts in solution in sea-water may be taken, in ordinary sea-water as $3\frac{1}{2}$ per cent. by wei ht, to about $24\frac{1}{2}$ per cent. by weight in the case of the Dead Sea, a cubic foot weighing respectively 64·05 lbs., and 71·175 lbs.

Cement mortar, or concrete used for general purposes, can be mixed with fresh water, which, of course, should be as clean as possible, and free from much lime or acids; but if the work is on the sea front, and it is convenient to do so, there is nothing to prohibit sea water being used for mixing. All experiments indicate that the quantity of water used in mixing cement is of great importance, and as a rule, less water is required when salt water is employed, usually about 5 to 12 per cent. less.

The tensile strength of cement is reduced if too much water is employed, and the quantity should be consistent with proper mixing and induration, as the strength is thereby increased; but, on the other hand, it has been stated by experimenters that the difference decreases considerably with age.

Air holes occur in cement mixed too stiffly, which should always be removed; and after the water has been added, the concrete, when thoroughly mixed, should be put into its permanent place, and not be allowed to stand for any length of time after it is ready

for use, unless there be particular reasons to the contrary.

It cannot be said that the relative value of sea and fresh water has been established, and it must, at present, be rather considered as one in course of settlement; but there does not appear to be anything yet determined that necessitates sea-water being regarded with suspicion, if it is clean, but as ordinary sea-water is said to contain about 0·31 grain of chloride of magnesium, and 0·21 grain of sulphate of magnesia in every 100 grains, it may be preferable to use fresh water.

The water should preferably have a temperature not less than about 50°, or more than about 80° Fahrenheit, and at 75° it has been found to set at about the quickest rate.

Mr. W. Maclay made upwards of 7000 experiments on Portland cement, vide the "Transactions of the American Society of Civil Engineers," vol. vi., and found among other results, that the effect of lowering the temperature appeared always to be a lessening of the activity of the cement, while raising the temperature increased the rapidity of the setting, and the effect of age was to lessen the influence of temperature. When the water was at a temperature of 70° to 80°, and the cement, when moulded, at 40° to 60°, the greatest tensile strength was obtained; some 10 to 20 per cent. more than at a 10° lower temperature. The results showed that Portland cement should not be mixed, or moulded, at a low temperature, or be dried in a high one. All temperatures are on the Fahrenheit scale.

In hot climates especially, gravel, stone, sand, and all aggregates, should be damped before they are mixed with the cement. From 5 to 7 per cent. of water by weight of the dry aggregates is sometimes used, the quantity varying according to their porosity; but the materials should only be damp, and not add much to the amount of water allowed for the cement; and yet be sufficient to prevent the cement being deprived of the moisture necessary for it to set and become indurated.

If Portland cement mortar is used in brickwork, the bricks should be soaked for some time before being laid. A few tests will determine the time required to prevent any water being extracted from the cement, or the mortar will be more or less pulverulent, as it then cannot set properly, and some of the lime is likely to be afterwards dissolved by any percolating water.

Portland cement concrete, if properly mixed, of good quality, and completely protected from frost during mixing and setting, for all practical purposes may be considered when set, as not materially affected by it. The prosecution of a work, especially one of repairs, may, however, be so urgent that it may be absolutely necessary to make and deposit concrete when the temperature is below freezing point, viz. 32° Fahrenheit. Hot water is occasionally used for mixing under such circumstances, which is objectionable. In any case the water should not have at the time of mixing a temperature above 80° Fahrenheit. Salt is sometimes added to the water; but both heating the water and the addition of salt to it are expedients, and should, if

possible, not be adopted. See Chapter V. for the effects of frost on the setting of Portland cement.

Preferably, no concrete should be made when the thermometer registers much below 40° Fahrenheit, for water from the temperature of about 39° expands as it becomes colder, but, on the other hand, contracts in reducing the temperature to about 40° Fahrenheit; and its expansive force, from the state of maximum condensation to the freezing point, is exceedingly great.

Mr. P. J. Messent, on the Tyne, tried mixing concrete in a diving-bell, but found that it did not succeed. In the first experiments the materials were mixed and filled into the bags in a dry state, but on examining them, it was found that they had sometimes caked on the outside before the water reached the central portion.

According to Mr. Dyckerhoff's experiments in 1883, concrete is stronger if made by adding cement mortar to gravel, instead of mixing cement and gravel direct; and the strength of concrete was found to be much greater when mixed in the air and afterwards immersed than if it was moulded under water, which it should not be.

Some specifications require the cement and sand to be first mixed dry, and the gravel added afterwards, also in a dry state, in order to make the mortar more uniform; and this method before mixing with water is to be recommended.

CHAPTER IX.

DEPOSITING CONCRETE IN WORK.

In layers—Punning—Methods of deposition—Expansion and contraction, and precautions against their ill effects, &c.

PORTLAND cement concrete should be deposited when it is thoroughly mixed and fresh, and be carefully trimmed and gently rammed if deposited in layers or pressed together with a shovel, which increases the strength by adding to its density, as is shown by its losing from 5 to 10 per cent. of its volume when mixed, and before deposition and ramming. Violent punning should not be allowed, for the object of ramming is to press the particles together *with a film of cement surrounding each*, and not to make the *bare* surface of the aggregates come into contact, for then it is injurious, and it is better omitted if it is not certain it will be properly effected. But in any case it should be done directly the concrete is deposited, and should not be long continued, in order that the process of crystallisation be not interfered with, which commences directly upon moisture being applied; and it is not advisable to pun large masses of concrete if deposited in bulk, as the outside surface may then be made denser than the interior and the concrete become of unequal consistency; but if placed in layers, gentle punning is

advantageous, and particularly so in thin work, such as walls, arches, floors, &c.

When the only stones available for use in concrete are of a soft nature, such as sandstone, punning, unless carefully and gently done, may break the stones; if so, as their entire surfaces will then not be encircled with Portland cement, weak places in the mass will be caused, and some of the stones will not be held together by cement, but will be in simple contact. Great care should be taken to obtain uniformity, and equal rate of setting, in order that there may be no partially set and soft places, and others hard and thoroughly indurated, which will very probably cause cracks in the work, due to unequal settlement, expansion, and contraction, and therefore the time should be fixed at which concrete should be deposited after mixing, and be adhered to as much as possible. Unless the urgent exigencies of the work require otherwise, as in most marine work, it is well if the layer of concrete deposited in one day does not exceed about 18 to 24 inches in depth, but not less than 18 inches, because the joint of each layer is temporarily somewhat weaker than the solid portion. In preference to an increase of the thickness of the layers the area over which the concrete is to be deposited should be enlarged proportionally in order that the required daily quantity of concrete can be used and progress not retarded.

It is sometimes specified that three days shall elapse before a fresh layer is deposited, but as expedition is almost always necessary in public works, such a length of time cannot often be allowed. The advantages

claimed for the system of depositing concrete in steps are that there is more homogeneity of construction, the chance of vertical fractures is avoided, and no great weight is suddenly placed upon the foundations, and therefore unequal settlement is improbable.

The top bed of each layer should be roughed, thoroughly brushed, cleaned, and well watered with cement grout, in order to bond to the next stratum, and the layers should be of uniform thickness to ensure equal settlement, and to prevent cracks.

Concrete should not be tipped into the work, but be gently shovelled into position on the level if possible, and it should never be thrown or cast in from a considerable height, or more than from 5 to 6 feet, as such action will separate the particles, and make air holes or bubbles in the mass; and it should be carefully punned if placed in layers and be gently deposited directly from barrows with as little fall as possible in order that the heavier ingredients may not sink to the bottom, and to ensure that the concrete will be homogeneous and not in layers of unequal strength. If a mixing-stage at the bottom of the foundations cannot be constructed, or the concrete be lowered by a crane in skips with opening bottoms, which is a method to be preferred, and provided it is necessary that the mixture should be gently dropped into its place down a shoot, or inclined plane; in order to counteract the separation of the particles and prevent their forming separate lines in the work, the concrete should after deposition be at once turned over or remixed without any addition of water, and

then be gently shovelled into its place, trimmed, and punned, if in layers; but there is seldom occasion for this, as it can be lowered on an inclined plane in a low-sided truck or box on wheels.

No concrete should be deposited in water when pumping operations are proceeding, as some of the cement may then be washed out.

When concrete is deposited against brickwork, or masonry, the surface should be watered, or washed with a cement grout in order that the concrete may not be deprived of the moisture necessary for its complete induration; and if different mixtures are used, unless there are cogent reasons to the contrary, the richer in cement, which necessarily has the greater adhesion and cohesion, should be placed against the work already set.

When large stones are used for bonding concrete, they should be thoroughly saturated to prevent them extracting the water necessary for the Portland cement to set properly and harden, and should be placed not nearer than 1 foot apart, and 2 feet is to be preferred, and their weight should not exceed 3 or 4 cwt., or they may cause depressions and irregularities. They can be lowered by a crane, and should always be deposited immediately the concrete is spread, and care be taken that no vacuities occur. Their especial use is to bind one day's work to the next. Great care should be taken that all their surfaces are in contact with the concrete, so that it does not become a kind of common rubble work joined by a very weak mortar, and, although the stones are intended to increase strength, that they do not cause weakness.

When concrete has to be deposited in pockets between thin walls, as it may have occasionally to be in bridge abutments, piers, dock-walls, &c., unless the Portland cement is one possessing all the qualities necessary for soundness which have been described, has been thoroughly air-slaked, and mixed with plenty of water, the brickwork or masonry walls may become damaged by the expansion of the concrete. When so used it should be deposited in thin layers. Any expansion may generally be noticed by the concrete deposited in such pockets becoming curved at the top after having been flat when placed in the work.

Freshly mixed, or plastic concrete, if deposited gently in the sea will stand in a mound at an angle of about 45°, or a slope of 1 to 1.

With respect to the expansion and contraction of Portland cement and concrete it is referred to in Chapter III.; here the effects of cracks so caused are considered.

It is doubtful if an authenticated instance has been recorded of serious effects to cement or concrete, after it has set, being *solely* produced by the degree of heat, or cold, usually prevalent in temperate climates, provided cracks and fissures do not exist in the cement or concrete, and that water cannot percolate into the mass, and that the necessary care has been taken in making and depositing the concrete and in the selection of the materials. Generally it may be considered that cement, after having set, is not injuriously affected by changes of temperature.

During the operation of setting, if possible, the

temperature should not be below 40° Fahr. on the ground, or more than about 90° in the air, in order that there may not be any expansion, by cold below about 40°, of the water used in mixing, or a detrimental abstraction of moisture either by heat, the sun's rays, or drying winds.

In countries subject to great variations of temperature, if concrete is used in large masses, and is exposed to the sun, it has been found that it expands, contracts, and shows cracks, and therefore, if it can be done, the concrete *in sitû* should be protected from the sun's rays until it has thoroughly set.

At Buenos Ayres, Mr. Higgin overcame this difficulty by introducing at intervals strips of thin plate iron. They were withdrawn before the concrete was fully set, and the joint left was made up with cement mortar.

Another method, sometimes adopted to provide against cracks and fissures, especially in thin work, owing to variations of temperature during the operation of setting, is by the use of cross-panelling of lath boards $\frac{3}{8}$ inch in thickness at intervals of about 10 feet left in the work, but carefully covered.

It has also been found that if long concrete walls are not constructed in greater lengths than about 40 feet, that they do not crack or fissure in ordinary weather, provided the concrete is good and the necessary precautions have been taken in depositing it.

Attention to the following details will lessen the deleterious effects of expansion and contraction:—

The quantity of magnesia in the Portland cement

should not exceed about 1 per cent., and no carbonate of lime should be present in it when used.

The Portland cement should be ground very finely.

There must be no tendency in the cement to "fly" or "blow."

The Portland cement must be thoroughly air-slaked.

The temperature of the water used in mixing should not be less than about 40° Fahr.

The quantity of water used in mixing should be reduced to a minimum, consistent with that required for perfect setting and induration.

The temperature of the air, or the ground, in or upon which the concrete rests should not be less than 40°, nor that of the air more than about 90° Fahr.

The composition, mixing, and depositing of the concrete should be equal and regular.

The concrete, if possible, should be deposited in layers, as it reduces any expansion, and not in large masses; and if in layers, it should be gently punned and all air bubbles removed immediately on deposition.

If concrete must be deposited in large masses it can be subdivided by vertical divisions or thin partitions, which should be afterwards filled with strong concrete. In submerged work, from low water level to the top of the superstructure is the portion of the work most subject to cracks and fissures. Vertical cracks much more frequently appear than horizontal.

Variations of temperature during the operation of setting should be reduced as much as possible.

The sun's rays, drying winds and draughts, should be kept from the concrete until it has set.

No wall length should exceed about 40 feet without it being temporarily unattached to the next length.

In hot and very variable climates, thin iron plates, or lath strips, can be introduced at intervals, the former temporarily, the latter permanently; but all openings must be carefully filled with strong Portland cement concrete.

When only a moderate tensile strength of the Portland cement is required, the lime in the Portland cement is of a comparatively small percentage, and sufficient water is used in mixing to enable the process of setting to be perfected throughout the mass, and all other precautions are taken to produce a sound concrete, and it is protected from the sun's rays or drying winds, it may not be necessary to erect a concrete wall in separate lengths in order to allow for expansion and contraction. However, in a long wall very small cracks, generally called hair-cracks, usually appear when nothing has been done to counteract the effects of contraction and expansion, and they should not be allowed to remain, as by the action of air, rain, or the impinging force of the waves they may soon be increased, and although they do not necessarily show that the concrete is decaying or becoming disintegrated, as they may be simply caused by the contraction of a solid mass, it is necessary to fill them. In winter they are usually the wider, and a crack that may then be plainly seen, it may be difficult to discover by the eye in summer. Such hair-cracks may not appear at once, as the elasticity of cement decreases after some time, although its compressive strength and hardness increase. Such

cracks have been stopped by soft cord being first soaked in tallow or grease to prevent the water reaching the threads or twists, it is then caulked into the fissures. This is used as a temporary remedy previous to repairing by filling in with a rich Portland cement mixture.

As occasionally it has been suggested that gypsum or plaster of Paris should be added to reduce any tendency to crack in a Portland cement, it may be well to state that reliable experiments have shown that adding from 1 to 5 per cent. of gypsum increases the expansion instead of lessening it.

As stated in Chapter III., expansion may be disregarded under the conditions therein mentioned, but contraction will occur, visible or otherwise, and may be much lessened by adopting the same means as those used to guard against expansion, and by gentle punning and face protection until the concrete has set and hardened.

CHAPTER X.

TABLES OF STRENGTHS.

The approximate comparative tensile strength of different mixtures of Portland cement and sand—The approximate comparative tensile strength of different mixtures of lime concrete—The approximate proportion between the tensile and compressive strengths of different mixtures of Portland cement and lime concrete—The approximate comparative compressive strength of Portland cement and lime concretes.

Reference to the following tables will be found convenient when deciding upon the proportions of concrete. They give a general idea as to the approximate relative strengths of different mixtures of cement, lime, and aggregates, and are deduced and calculated from some tests appearing in a paper, volume lxii., of the 'Minutes of Proceedings of the Institution of Civil Engineers,' read by Mr. John Grant, M. Inst. C.E., whose experiments are undoubtedly the most reliable extant, as they were made under the conditions that exist in practice, and with the greatest care. They have been here especially constructed in an entirely distinct form, in order to ascertain the approximate comparative value of Portland cement and different limes mixed in various proportions with aggregates.

With respect to lime concretes mixed in the pro-

portions named in the tables, it should be noted that, if kept wet, their tensile strength increased considerably, and in no case, the experiments proved, was it diminished; but with Portland cement concrete, however, the relative increase of tensile strength, when kept wet, was less than that of the lime concretes, although, as a rule, more when kept dry.

Mr. Grant stated, that "from their generally lower strength and slower action it is much more tedious to test limes than cement, and it would take some years to get a sufficient number of results to form the basis for a sound judgment."

The appearance of fracture, or giving way, of Portland cement concrete under compression experiments, usually commences with from 40 to 20 per cent. less weight than that required to crush a block; but in the case of so variable a material as concrete there is no fixed limit.

It will be noticed that the compressive strengths of some of the lime concretes vary very irregularly, and not according to the quantity of lime present in the mixture; some lime concretes increasing in compressive strength as the lime is lessened, whereas the tensile strengths generally decrease as the quantity of lime to sand becomes less; but with Portland cement concretes both the tensile and compressive strengths generally decrease in strength nearly regularly as the amount of cement becomes less, and quicker in proportion in compression than tension.

The briquettes in all the tensile tests were of the

gently curved form designed by the late Mr. Grant, of the then Metropolitan Board of Works. 1·5″ × 1·5″ = 2·25 square inches. Briquettes kept dry.

Tensile Strength.

Tests end of twelve months. Sand weighed 96 lbs. per bushel. Each number the average of five tests. Briquettes kept dry.

The number indicates the relative strength, neat Portland cement being taken as 100.

Portland Cement. 114 lbs. per Bushel.	Portland Cement. 120 lbs. per Bushel.	Proportions by Volume.
100	100	neat
72	64·5	sand 1 to 1 Portland cement.
51	38	„ 2 to 1 „
42	32·5	„ 3 to 1 „
35	29	„ 4 to 1 „
30·5	24	„ 5 to 1 „
24	18	„ 6 to 1 „
11	12·5	„ 8 to 1 „
9·5	9·5	„ 10 to 1 „
6·9	7·5	„ 12 to 1 „
The tensile strength per square foot of this neat Portland cement = 30·26 tons.	The tensile strength per square foot of this neat Portland cement = 35·5 tons.	

Tensile Strength.

Briquettes kept dry. Sand 96 lbs. per bushel.

Grey Lime.

The tensile strength of grey lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately 3·23 tons.

Relative Strengths.	Proportions by Volume.
100	3 to 1
87·5	4 to 1
60	5 to 1
41·5	6 to 1

Selenitic Grey Lime.

The tensile strength of selenitic grey lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately 8·23 tons.

Relative Strengths.	Proportions by Volume.
100	3 to 1
51	4 to 1
42·5	5 to 1
31	6 to 1

Lias Lime.

The tensile strength of lias lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately 2·6 to 3·09 tons.

Relative Strengths.	Proportions by Volume.
84 to 100	3 to 1
57 to 102	4 to 1
44·5 to 67·5	5 to 1
38 to 48	6 to 1

Selenitic Lias Lime.

The tensile strength of selenitic lias lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately 5 to 5·9 tons.

Relative Strengths.	Proportions by Volume.
100	3 to 1
64·5 to 68	4 to 1
36 to 48	5 to 1
31·5 to 57	6 to 1

Selenitic Lime.

The tensile strength of selenitic lime mortar per square foot, proportions, 1 of lime to 3 of sand, is approximately 8 tons.

Relative Strengths.	Proportions by Volume.
100	3 to 1
64	4 to 1
59	5 to 1
47	6 to 1

Note.—The numbers here given of the tensile strengths of limes show the proportionate approximate relative strength of different mixtures of the *same* lime, and not the relative tensile strength of the different limes. 100 is taken in each case, for ease of comparison, as the constant for a 3 to 1 mixture, i.e. 3 of sand to 1 of lime. The sand and briquettes were the same in each case, and all the tests under like conditions.

Proportions between the Tensile and Compressive Strengths of different Mixtures of Lime and Cement Concretes.

6 to 1.	Proportionate Strengths.	
	Tension.	Compression.
Grey lime concrete	1	7·6
Selenitic grey lime concrete	1	7·2
Lias lime concrete	1	7·7 to 19·7
Seleuitic lias lime concrete	1	5·1 to 20*
Selenitic lime concrete	1	7·1
PORTLAND CEMENT CONCRETE	1	13·6 to 13·9

* Selenitic Rugby lias.

The tensile strength of a 6 to 1 Portland cement concrete is, approximately, 6·34 to 7 tons per square foot.

8 to 1.	Proportionate Strengths.	
	Tension.	Compression.
PORTLAND CEMENT CONCRETE	1	20·5 to 22

The tensile strength of an 8 to 1 Portland cement concrete is, approximately, 3·4 to 4·5 tons per square foot.

10 to 1.	Proportionate Strengths.	
	Tension.	Compression.
PORTLAND CEMENT CONCRETE	1	15·7 to 18·5

The tensile strength of a 10 to 1 Portland cement concrete is, approximately, 2·9 to 3·3 tons per square foot.

12 to 1.	Proportionate Strengths.	
	Tension.	Compression.
Portland cement concrete	1	11 to 18

The tensile strength of a 12 to 1 Portland cement concrete is, approximately, 2·1 to 2·9 tons per square foot.

$$\frac{\text{Pounds per square inch}}{15\cdot 5\dot{5}} = \text{tons per square foot.}$$

Tons per square foot $\times$ $15\cdot 5\dot{5}$ = pounds per square inch.

Compressive Strength.

Briquettes kept in a dry state. Each experiment is the average of ten 6-inch cubes. All proportions by volume, and all tests end of twelve months. Gravel and sand weighed 137 lbs. per bushel.

Taking the crushing strength of a 6 to 1 grey lime concrete as unity, the corresponding compressive strength is given of each kind of lime concrete named, and of Portland cement concrete mixed in the same proportions.

6 to 1.	Lowest.	Highest.
Grey lime concrete	1	1
Selenitic grey lime concrete	1·82	1·82
Lias lime concrete	1·12	2·26
Selenitic lias lime concrete	1·69	3·64*
Selenitic lime concrete	2·61	3·34

* Selenitic Rugby lias lime.

6 to 1.	114 lbs. per Bushel.	120 lbs. per Bushel.
PORTLAND CEMENT CONCRETE	9·88	8·47

The crushing strength of grey lime concrete 6 to 1 is, approximately, about 10·20 tons per square foot. The crushing strength of Portland cement concrete 6 to 1 is, approximately about 87 to 101 tons per square foot.

Compressive Strength.

The proportional crushing strength of grey lime concrete 6 to 1 to 8 to 1, is as 1 is to 0·45.

8 to 1.	Lowest.	Highest.
Grey lime concrete	1	1
Selenitic grey lime concrete	1·66	1·66
Lias lime concrete	2·33	2·41
Selenitic lias lime concrete	4·27	7·44*
Selenitic lime concrete	3·32	4·74

* Selenitic Rugby lias lime.

8 to 1.	114 lbs. per Bushel.	120 lbs. per Bushel.
PORTLAND CEMENT CONCRETE	16·61	19·94

Taking the crushing strength of an 8 to 1 grey lime concrete as unity, the corresponding crushing strength of each kind of lime concrete named, and Portland cement concrete, mixed in the same proportion, is given in the preceding table.

The crushing strength of grey lime concrete, 8 to 1 is, approximately, about 4·6 tons per square foot.

The crushing strength of Portland cement concrete, 8 to 1 is, approximately, about 77 to 92 tons per square foot.

Compressive Strength.

The proportional crushing strength of grey lime concrete 8 to 1 to 10 to 1, is as 1 is to 1·13.

10 to 1.	Lowest.	Highest.
Grey lime concrete	1	1
Selenitic grey lime concrete	1·57	1·57
Lias lime concrete	1·64	2·21
Selenitic lias lime concrete	1·97	4·06*
Selenitic lime concrete	2·60	2·96

* Selenitic Rugby lias lime.

10 to 1.	114 lbs. per Bushel.	120 lbs. per Bushel.
PORTLAND CEMENT CONCRETE	10·3	10

Taking the crushing strength of a 10 to 1 grey lime concrete as unity, the corresponding crushing strength of each kind of lime concrete named, and Portland cement concrete mixed in the same proportion, is given in the preceding table.

The crushing strength of grey lime concrete 10 to 1 is, approximately, about 5·2 tons per square foot. The crushing strength of Portland cement concrete 10 to 1 is, approximately, about 53 tons per square foot.

Compressive Strength.

12 to 1.

The proportional crushing strength of Portland cement concrete 10 to 1 to 12 to 1 is as 1 is to ·69.

The crushing strength of Portland cement concrete 12 to 1 is, approximately, about 37 tons per square foot.

CHAPTER XI.

FACING CONCRETE. CEMENT GROUT.

Use of systems—Necessary precautions—Joints—Grout.

Mr. Bernays, at the Chatham Dockyard extension works, extensively used a system of facing concrete walls made of 12 parts of river Medway gravel to 1 of Portland cement. He faced the dock and retaining walls with success with 9 to 10 inches in thickness of 4 to 1 concrete, consisting of 4 parts of broken slag or flint, 2 parts of sharp sand, and 1 part of Portland cement. This face concrete was so hard that it might be cut into for receiving bolts for fixing machinery. With such a mixture the thickness of facing should not be lessened.

There is no doubt that the plan of providing quay and other walls with a facing of stronger concrete is very effectual, as, say, an 8 to 1 to 12 to 1 concrete does not afford a sufficiently impervious, even, smooth, and equally hard face, without taking into consideration the appearance of the work. The same precautions should be observed before putting on the concrete facing as are referred to in Chapter IX., "Depositing Concrete in Work."

The face concrete should be well smoothed when wet,

and this should be done immediately on deposition, so as to obtain an equal appearance, and avoid patching it afterwards, as in that case it will usually not dry exactly the same colour, and will show its edges, particularly against the other previously set concrete. In order to ensure a good joint between the work that has already set, and that about to be deposited, it is advisable to pick over, or serrate, the surface of the set concrete, so as to ensure a rugged face to which the face concrete can adhere, and if ordinary precautions are taken, there is no reason to fear that the facing will separate from the main body of the wall, as is often the case with imperfectly faced brickwork, and ashlar faced rubble masonry. Consideration of the regularity and thoroughness of the bond over the entire face to be obtained with concrete, shows that the objections against face brickwork, or masonry, do not apply to a facing of concrete. It is acknowledged that the bond between the face and the backing of brickwork, or masonry, is not nearly so strong as in the body of the work; but in cement concrete facing, with the usual precautions always taken in depositing a layer upon a layer of concrete, the junction of the face concrete with the main body cannot be weaker than the mass, but it is probably stronger; because the face concrete being richer in cement than that to which it is joined, and the cement being the material which alone binds the mass, it follows that the holding power of the face concrete is greater than the cohesion of the concrete in the main body of the work, and to which it is as perfectly joined as any layer in the mass.

No grouting with liquid concrete, or rendering of plaster, should be adopted for face work, but the face concrete of a finer and stronger mixture should be filled in, worked, and pressed against the face mould, or plank, and all air should be expelled, or a smooth even surface will not be obtained. If such a surface is required the mould should have a planed timber face washed perfectly clean, and then a thin solution of soap, of the consistency of paint, can be applied over its surface before the face concrete is deposited; and the surface will be found to be smooth, even, and not mottled, if the mixture has been carefully and equally made.

It is preferable that the facework proceeds with the main work in order to have no joint with concrete which has previously set, as it is necessarily temporarily weaker, and not easy to make a coating adhere properly unless the facing is spread evenly immediately any frames or moulds are removed; but if the design of the work will not permit the face and main concrete to proceed *pari passu*, the richer, i. e. the concrete having the most cement in it should be joined to the poorer concrete, because the richer mixture has the greater adhesive strength, having more cement in it, and it should be noted that the cement alone holds the mass together.

Provided the necessary precautions are taken to have a clean and rough surface for the joint, freshly mixed or plastic concrete may be deposited without fear on that which has previously set. If a stronger substance is joined to a weaker, it is obvious the stronger cannot

give way before the weaker; and that, therefore, the joint of the fresh concrete with the indurated mass cannot be weaker than the main body of the weaker concrete.

When masses of concrete in walls have to be frequently joined, a bond can be made by fixing, as soon after deposition as possible, angular stones in the face, in a similar way to "toothing" in brickwork. Old short rails and pieces of iron, iron ties, and wire netting are sometimes inserted for bonding purposes, and abutting recesses are left in work, to be afterwards filled with a strong concrete.

A method sometimes used to clean concrete is by washing it with a strong solution of caustic soda, it being afterwards cleansed with clean water. Dirt has been removed by hard scrubbing brushes being applied to the face, then by thorough washing of the surface, it being afterwards wetted before the facework is applied. Also by applying a wash composed of water and chloride of lime, and by washing it away with water in about an hour.

No means should be spared to make a perfect and durable connection between the face concrete and the mass, and it is of the utmost importance that all submerged concrete should have an impervious and durable face, either by a facing, or by concrete face blocks set in Portland cement. Any protective coating should be of considerable thickness, and not a mere rendering, and although in exceptional circumstances it may be advisable to make the whole mass impermeable, a properly applied watertight coating should be sufficient

under ordinary conditions of work and reasonable inspection.

In the case of thin walls, or a water-washed surface in thin work, a coating of neat Portland cement from 1 to 2 inches in thickness, depending upon the degree of exposure, has been applied to all kinds of work such as walls, &c., by depositing it against the moulds or frames just before the concrete is put in position; the mass being gently pressed and rammed, so as to cause the cement facing to become incorporated with the concrete next to it, and be an inherent part of the mass without any joint with set concrete.

It is very important to prevent the deposition, or to remove any slime, silty or other matter that may adhere or rest upon any surfaces to be joined before adding fresh concrete, for, if this is not effected, water will percolate along such joints, and a concrete structure so erected will consist of separate masses or layers, with a silty film or dirty mortar joint, which has no reliable strength, and is not durable. It may be advisable to grout the top of any set concrete upon which any fresh concrete has to be deposited.

With respect to the composition of face concrete a proportion of 2 of clean and approved sand to 1 of Portland cement should not be exceeded for the mortar, and a $1\frac{1}{2}$ to 1 or 1 to 1 mixture is to be preferred in any exposed situation. If stones are used they should pass through a half-inch sieve, and not more than 3 or 4 parts of such stones should be mixed with the mortar.

It is not improbable that analytical chemists may dis-

cover an impermeable wash that can be applied to the surface of concrete, without deleteriously affecting its strength and durability, by closing the pores on the surface and making it waterproof; and also a durable coating in both fresh and salt water, and in any situation in which engineering structures are placed, see Chapter XIV. as to some solutions suggested by Dr. Michaëlis. Dr. T. Koller has stated that 1 of common salt to 3 parts of quicklime makes a wash as hard as cement for buildings, and that it cannot be removed by scrubbing. The effect was considered to be due to the hygroscopic action of the salt, which absorbs water, and permits of the speedy combination of the lime with the carbonic acid of the atmosphere.

With respect to joints, some experiments by Lieut. Cresswell, R.E., 'Roorkee Treatise,' vol. viii., to ascertain the transverse strength of different thicknesses of joints in brickwork in lime mortar, consisting of 2 parts of steam-ground, coal-burnt, kunker-lime to 1 of sand, gave the following results:—Bricks were sand-moulded, kiln-burnt, and were carefully gauged and sorted. Joints $\frac{1}{8}$ to $\frac{1}{4}$ of an inch in thickness were found to be stronger than any other proportion, $\frac{1}{4}$ of an inch being the best thickness. Taking the strength for $\frac{1}{2}$ and $\frac{3}{4}$ inch in thickness joints as 1, that of $\frac{1}{16}$ of an inch was 1·32, $\frac{1}{8}$ of an inch was 1·49, and $\frac{1}{4}$ of an inch 1·55.

Mr. Grant's experiments to separate bricks cemented together with Portland cement in the proportions of 1, 2, 3, 4, and 5 to 1, and with lime mortars, 2 to 1 of blue lias, 2 to 1 of Dorking, and 2 to 1 of chalk lime

mortars, showed that pressed gault bricks had the least amount of adhesiveness, partly because of their smooth surface, and partly because in making them some oily matter is used for lubricating the dies of the press through which they are passed before being burnt. In the case of perforated gault bricks the cement mortar seemed to act as dowels, and the results were high. The Suffolk and Fareham red bricks, which each absorb about 1 lb. of water per brick, or the wire-cut gault bricks, and those of a somewhat porous nature, adhere much better than the Staffordshire blue bricks, which are non-absorbent, taking about 1 to 1¼ oz. of water per brick, and have a smooth or glazed surface.

In setting stones or bricks upon mortar, which should be soft and not fluid, they should be gently slid and struck with a tool in order to expel the air, and not be simply placed upon the mortar. The bricks or stones should always be well watered and soaked, so as not to absorb any of the water necessary for the proper setting of the Portland cement, or lime, in the mortar. The amount of moisture a brick or a stone of a certain bulk will readily absorb can be tested by experimental submersion. Many bricks of ordinary size will absorb fully 1 lb. of water. Experiments have shown that if two bricks as taken from the kilns are joined together by mortar they can be easily separated, but if they are properly wetted the normal cementitious value of the mortar is unimpaired. It is well to remember that the usual forms of bond were designed more especially to distribute vertical pressure, and not with the particular object of withstanding lateral thrust, such as abutments

and walls backed with earth have to sustain, therefore a perfect joint is of much importance in order to obtain a monolithic mass.

The specification of the granite masonry joints of the Putney Bridge, over the Thames, London, contained the following words, "The whole of the masonry to be set flush in beds of mortar composed of 1 of Portland cement to 1 of sand, and properly grouted. The joints not to exceed $\frac{3}{16}$ of an inch. Grout nicks to be cut in all vertical joints of the ashlar work." At the Bishop's Rock lighthouse, the granite blocks were grouted in Portland cement and clean granite sand in equal proportions by measure. About $\frac{1}{4}$th to $\frac{1}{3}$rd, usually nearly $\frac{1}{3}$rd, of a cube yard of mortar is contained in a cube yard of rubble masonry, and $\frac{1}{4}$th of a cube yard in a cube yard of brickwork.

The strength of cement and lime mortars depends, apart from the proportion of the sand, upon it being clean and purely silicious; in the case of thin joints, where imperviousness and durability are of the utmost importance, the very best sand should be alone used, or induration will not ensue. If the mortar used or to be used for a joint has been disturbed after partly setting, it will not adhere again properly, or retain its original cementitious value. When work has to be pointed, the joints should be raked out as far as possible, well brushed, cleaned, and wetted, and be pointed with neat cement.

With regard to grout, the object of it is to penetrate and fill all depressions and cavities in work, and make them air-tight and level with the surfaces on every

side, and also to keep the unclosed work in a sufficiently moist condition for proper setting of the mortar, but it should not be used in so great a quantity as to supersede or take the place of a proper mortar joint. Portland cement grout, properly mixed and applied, is of great value in concrete work, as well as when used in brick-work or masonry, and many leaks in docks and walls have been stopped satisfactorily and very economically by its use. As leaks appear by pressure, it is clear that cement grout can be successfully used under such slight pressure, but as the surfaces of the fissures are generally rough and afford a hold, apart from any chemical combination of the grout with the fissured mass, the weight of the grout also presents a counter-acting force to that of the leaking, and the pressure may be thus neutralised. In Chapter V. a reason has been stated why concrete does not set under hydrostatic pressure, but if such pressure was a little more than balanced, the effect would be that the grout had to set in still or nearly still water; and it has yet to be proved that cement grout will set under any but the very slightest flow of water or solidly fill the interstices of a mass under such a condition. If, however, a counterbalancing pressure is maintained, the cement grout should set. Mr. Kinipple in some cases used a 3 to $3\frac{1}{2}$ inches in diameter grouting pipe having a funnel-shaped mouth, and perforations at the discharging end, the holes being $\frac{3}{4}$ of an inch in diameter for about 1 foot up. It must be inserted well into any mass to be grouted. He stopped a leak in an old graving dock at Greenock by neat Portland cement grout

poured down and allowed to permeate till no more grout could be inserted.

In submerged work, a grout to fill up joints, &c., should consist of neat cement, and not of sand and cement, as owing to the diluted condition of the mixture, the sand becomes separated from the cement, the heavier from the lighter material. It should be as thick as possible in order to lessen the disintegrating effect of the excess of water. In work exposed to the air the weakest mixture employed is 1 of Portland cement to 1 of sand.

Mr. Kinipple, who has used Portland cement grout in very considerable quantities and in important and severely strained structures, has stated that to make the cement grout reliable the cement must be finely ground, and has mentioned as the lowest test that at least 90 per cent. should pass through a sieve of 6400 meshes to the square inch, and that the finer the cement the better the grout, and further that coarse cement is useless as a grout, and cannot be easily discharged, as the coarse particles obstruct the flow of the cement in the pipe, and that the only way to mix the grout so as to be reliable and good in every way, is to mix the cement to a thick paste by gently adding water in small quantities, and stirring up the mass until it will leave a bucket and flow down the discharge pipe, which it should do rapidly, but gently. A 1 foot column is found to balance a 2 feet head of water, and so for any other reasonable depth. Mr. Kinipple also found that the weight of cement grout to render solid an ordinary rubble and shingle mass

was about $\frac{1}{9}$th of the weight of the stones, but, of course, this will vary according to the character and size of the stones.

Some repairs of the foundations of the Lake Croton Railway bridge, U.S.A., see 'Transactions of the American Society of Engineers, 1891,' were effected by means of grouting by pipes; the object was to cement together a mass of stone cribwork that projected several feet beyond the masonry pier built thereon, and so dispense with a cofferdam or caisson. A hand pump was used to force down the grout, having a long nozzle of $1\frac{1}{2}$-inch pipe, which was inserted as far as the bottom of the hole, and water pumped through for a few minutes, then the suction hose was suddenly transferred to a reservoir of grout consisting of 1 of Alsen Portland cement and 1 of sand, mixed immediately before use. It was found to be desirable to make the length of pipe as little as possible. Two or three barrels only of the grout at a time were forced slowly through; then the nozzle was withdrawn, the hole being kept open, and the work being recommenced at another hole, grout being seldom forced into the same hole twice in one day. The idea was that the cement in the quiet water would accrete on the surfaces of the irregular stonework, at and below the level of injection, and that by slight consecutive injections, at proper intervals of time, the voids between the stones would be filled. It was found, on the foundations being inspected, that at about 6 feet from the nearest nozzle-hole some of the stone had been coated with $\frac{1}{2}$ an inch of cement. No loss of cement through the rip rap, i.e. random stone, could be traced,

and the system was successfully used in depths up to 28 feet of water. Mr. R. L. Harris, M. Inst. C.E., states that this mode of procedure may be used with equal advantage for gravel, sand, and even quicksand, and for many subaqueous structures. It may here be written that it has been so applied in a few cases.

CHAPTER XII.

CONCRETE ARCHES.

Footings—Some special methods of concrete construction.

In arched concrete work, in order to prevent the chance of the face becoming brittle, the surface should be covered and in a damp state until it is thoroughly set, and the moulds, i. e. the close boarding enclosed at the sides and set upon the centering, and the centering should be allowed to remain as long as possible; and, except in small arches which would not be subject to any severe strain, they should not be struck before 28 days have elapsed, instead of a week or ten days, usual with brickwork, and 15 days should be the minimum, although concrete arches of considerable span sometimes expand on setting sufficiently to lift themselves partly or wholly from the centering.

The interior of a concrete arch, by interior is meant that portion commencing about 4 to 6 inches from the faces, will usually be found to be more dense than the surface.

The great care necessary in the construction of concrete arches renders their employment undesirable for such purposes as railway underbridges, subject to a heavy and quickly rolling load, although admirably adapted for the abutments, wingwalls, and parapets, &c.,

of such bridges. The cost of arches in concrete under such circumstances will generally be found to equal that of a brickwork or masonry arch; and there is difficulty in obtaining men accustomed to such operations in the construction of ordinary railroads; and on railway works extending over several miles in length, it is seldom that the inspection and supervision of any particular structure can be as thoroughly performed as on works concentrated upon one site, such as harbours, docks, and sea-walls, &c., large viaducts and aqueducts; and without such constant supervision no concrete arch should be trusted, as it cannot be certain that it is possessed of uniform high quality.

Also, the proper inspection of brickwork and masonry is more easily effected than concrete, and does not require the constant attention that is so absolutely necessary in concrete arch work.

On railways it is frequently imperative that the centering should be struck within a few days of erection, which must not be done with concrete arches, especially when destined to bear severe and sudden loads.

In situations where the rolling load is heavy and the speed great, the soil of a yielding nature, and the bridges isolated, there is no saving in expense in the employment of concrete for arches; on the other hand, if the load is stable and invariable, and several arches have to be erected, it is economical and safe to employ concrete. It is not advisable to adopt concrete for skew arches. The strain upon the triangular portion of the arch which forms the part that is not square with both abutments being compound, and the strength of such tri-

angular portion being dependent upon the cementing of the materials, or adhesive strength of the cement, which is much less than the tensile strength, and is very much less than the compressive strength, the stability of a concrete skew arch may be injuriously and unequally affected. The thrust of a skew arch being nearly at right angles to the abutments, the strain on the acute angles is less than that on the obtuse angles of an arch, therefore there is a thrust from the central right-angled portion of the arch towards the faces, consequently the arch is not in compression only, for a torsional strain will be generated, and must be resisted by the tenacity of the material. The approximate ratio of the adhesive to the tensile strength, and the latter to the compressive strength, are referred to in Chapters IV. and X.

If neither bricks nor building stone be available, and it is necessary that the centre line of the arch be at an angle with the road or railway, the concrete skew arch can be constructed on the rib system, each rib being square with the abutments; but the ribs should be well and frequently strutted and firmly tied together by iron struts and ties, or they will not be stable. The struts and ties are especially required at the springing level, and should be continued at intervals along the arch not exceeding about 6 or 7 feet. The ties should bind each rib to the others. It is important to remember that if the arch is not firmly fixed at the springing, it will not be a simple arch, but an arched girder.

For the supporting arches of the parapet walls of breakwaters, the vaults of reservoirs, and arches generally that are square with the abutments, and not

subject to a heavy and quick rolling load, concrete is well adapted. They should be segmental for comparatively large spans, as the compressive strength of concrete is by far the greatest, and it should be exposed to that strain only as much as possible. Care should be taken that the curve of equilibrium will always be within the middle third of the ring, and that no lateral movement of the abutments, or piers, can take place; and as concrete in arches and beams breaks somewhat suddenly without giving much warning, it is obvious great caution must be exercised in constructing such important and thin work. For light work and small spans, such as 10 feet, the semicircular form can be adopted, as being, perhaps, the more easily constructed.

The arch should be kept damp until set, and the concrete be thoroughly mixed, mingled, pressed, and gently rammed between the moulds and centering, and great care should be taken that the moulds do not yield during deposition of the concrete, and until it has set, and that the arch is thoroughly combined and equal in strength, and with a view to this it is well if it be carefully rammed in the direction of the thrust.

The following are some methods of constructing arches in concrete:—

1. The building the arch of its full thickness throughout from the springing level to the springing level, which is to be preferred if its thickness is not more than about 2 feet at the crown, and the arch is not of large span.

2. Its construction by portions of the full thickness.

3. The building of layers extending throughout from

the springing level to the springing level, and the depositing layers upon those already set, until the required thickness is obtained. Applicable for segmental arches of considerable thickness, but care must be taken that the arch ring is a solid mass, and not in separate rings.

4. The arch to have a key of brickwork, masonry, or iron, and to be constructed according to systems 1, 2, or 3.

The deposition of the concrete commences at the springing level and proceeds on each side towards the crown, and a skewback can be especially constructed, if preferred.

The concrete in method 4 can be more easily rammed and punned, and as the arch is divided into two parts during construction, there is not so much chance of unequal strength of the concrete, or effects of expansion and contraction, but there must be a thorough connection between the brick, masonry, or iron keystone and the concrete, and skewback, if any.

The haunches on both sides are sometimes first executed, no water being allowed to accumulate upon them, then the central remaining portion of the arch, and after the arch is properly set, the spandrels are constructed. If the abutments to the springing of an arch are of Portland cement concrete, they should be allowed at least one month to become indurated, and be well backed with earth or otherwise supported before the arch is erected, so that no strain is brought upon them till they are thoroughly set.

To make concrete abutments or wingwalls for small

stream bridges, a few piles can be driven to a depth a little below the intended level of the foundations, just outside the extreme dimensions of the foundation, and around it at intervals of about 3 feet, allowing room for $1\frac{1}{2}$ or 2-inch planking, or corrugated iron sheeting, as the corrugations can be disregarded below the ground or water-level. The excavation can then be effected, and the concrete be carefully deposited with the usual precautions, either in still water allowed to rise to river level, or in the open air, as considered desirable. One objection to concrete arches for variable rolling loads is that the material being so imperfectly elastic, the arch may take a permanent set of too great moment, may crack, and finally break. Also, if the abutments yield or spread, the arch cannot change, or slightly alter its form, as an arch can composed of voussoirs, whether brick or stone, or of a material having considerable elasticity, such as steel and iron.

The difference between the crushing and tensile strengths of steel, wrought or cast iron, and bricks, is not nearly so great as that of Portland cement concrete, which should be remembered in the erection of any structures liable to a variable strain, and demanding a certain degree of elasticity; however, it is not intended to depreciate the value of Portland cement concrete for archwork, but only to state that it is not a material as well adapted for isolated archwork, which will be subjected to speedy, variable, and heavy rolling loads, as steel or iron, brickwork, or masonry, and that concrete archwork, subject to such strain, requires great care in and after erection.

As concrete arches are usually made of greater thickness than if constructed of brickwork or masonry, an additional thrust from this cause is created to that which would result from the employment of brickwork, which weighs about 16 to 20 per cent. less than Portland cement concrete; or stone, iron, or steel, and consequently an increased weight is brought upon the abutments or piers and the foundations.

The thickness of a segmental arch of concrete should always increase towards the haunches, according to the usual formula, and the backing should be deposited without delay.

It is advisable to make concrete for archwork richer in cement, or with less sand, than that of the other parts of a bridge, and with regard to the composition of Portland cement concrete in archwork, bearing in mind that it is the proportion of sand to Portland cement that principally affects the strength, see Chapter X., of tensile strengths of Portland cement mixed with different proportions of sand. Unless the whole mass of the arch must be impervious to water, it is here recommended that very little sand should be used in Portland cement concrete arches, or in beams to resist transverse strain, although the vacuities may be 10 per cent. or more of the mixture; and that the stone or rock concrete should be faced in the manner described in Chapter XI., in order to exclude water and air from the strain-bearing portion of the arch.

It has been found that rain will, in a few hours, percolate through a mixture of 6 of gravel to 1 of Portland cement when used from 3 to 6 feet in thick-

ness in archwork, such a mixture being too porous to be watertight.

If rock concrete is used, it is well if it be richer in cement at the junction with any brickwork, masonry, or concrete previously set.

The experiments of Mr. Colson on beams and flat arches of concrete showed the importance and necessity of guarding against the possibility of lateral movement in the slightest degree, in the supporting girders of a floor, as by so doing the supporting power of a beam is materially increased; and before loading 28 days at the least should be allowed to elapse, as at 14 days a beam will give way that will stand at 21 and 28 days, and at the latter date, when loaded. He also found that a straight beam of concrete, firmly supported at the ends, of 8 feet 3 inches span, with $4\frac{1}{2}$ inches bearing upon each pier, and 9 inches in depth, if made in arch-form with a $4\frac{1}{2}$ inches rise at the centre, was as strong as a straight beam, although a curved strip of concrete, rising at the pier on each side to a height at the centre of $4\frac{1}{2}$ inches, was taken away; always provided that the curved beam is firmly confined at the ends.

With regard to concrete footings, the object of a concrete base is to equally distribute the weight of a structure over the ground, and to form a monolithic mass upon which the superstructure can rest. They must therefore have sufficient transverse strength, and their projection beyond the face of a structure and their thickness should be calculated according to the load on it, the tensile strength of the concrete, and the safe

load on the foundation, and a factor of safety be allowed of 2 or 3 to ensure stability, and to compensate for unequal loading; the minimum thickness being not less than about twice the projection of the concrete from the face, for a pressure of 2 or 3 tons per square foot on the ground, and for 5 tons, $2\frac{1}{2}$ to 3 times; but, of course, it is advisable to calculate it in each case.

In Chapter XI. the value of Portland cement grout properly applied has been mentioned, and in addition concrete can be used in various ways to repair structures under water, for concrete blocks, bags about three-quarters full so as to conform and occupy a void of any shape, concrete deposited *in sitû*, can be employed, either singly or in combination.

As buildings that have been declared fireproof have given proof that they cannot wholly resist fire, the word fireproof is, in building construction, but a comparative term. Good Portland cement concrete, and well-burnt and thoroughly sound bricks carefully laid in good Portland cement mortar, are considered by experts, who found their views on the results of fires, to be about the most fireproof materials used in ordinary building construction; for all metalwork expands, and therefore, in order that it may stand, it requires full provision for a very large degree of expansion, even if it does not fail from other causes, and has a very destructive effect.

The quantity of acids in ordinary sewage is not sufficient to deleteriously affect sewers made of good sound Portland cement concrete, but the refuse overflow from chemical works may do so, as it would brick-

work, iron, and most materials. In such cases a vitrified invert can be used.

The most important recent methods of construction in Portland cement concrete consist in the employment of a metal skeleton, or wire netting, in combination with the concrete. The metal skeleton system simply consists of round or other shaped bar-iron trelliswork, having meshes of 2 to 4 inches, tied together at the intersections, the whole being embedded in Portland cement concrete. The expansion by heat of such iron-work is considered to be about the same as the Portland cement; the combination is therefore regarded as solid and durable, as iron so placed will not rust, for the cement is looked upon as water and air-tight. The chief idea of the construction is that the cement resists compression and the iron extension.

Another method of construction recently introduced is that called "The Monier." It has been used on a large scale in Germany, Austria, and Switzerland, for bridges, roofs, culverts, buildings, &c., and appears to be especially useful for concrete arches and roofs. The chief idea of the system is to strengthen the tensional resistance of Portland cement concrete, and to cause the compressive and tensional strength to be as equal as possible, instead of the wide divergence shown in Chapter X., "Tables of Strengths," and as wire wrought-iron netting can be more easily and equally incorporated or intertwined with Portland cement concrete in thin work, it appears to possess advantages over the solid bar or skeleton metal method of construction, for any expansion or contraction can

be better distributed. It is considered that the wrought-iron netting can be so introduced that the tensional stresses are taken by the wrought iron, and the compressive strains by the concrete, thus straining the materials to the best advantage. Some tests made in the building-yard of the Royal Hungarian Government at Budapest, showed that an arch constructed of the best Portland cement concrete would only sustain one-fifth of the load of an arch constructed on the Monier system. It is claimed that this method of construction combines lightness, cheapness in erection and maintenance, and increased strength, and the tests at present made, and the works so constructed, appear to warrant these claims.

CHAPTER XIII.

CEMENT AND LIME MORTARS.

Portland cement mortar—Superiority to lime mortar—Softening cement mortar—Mixtures of lime and cement mortar—Roman cement.

PORTLAND cement possesses quick indurating properties, not simply confined to the exterior skin, and will harden readily under water; but rich limes require time, and are slow and gradual in the process of hardening, and become indurated on the outside some time before the inside is set, and are therefore unequal in strength.

As foundations are frequently subject to the action of dripping water, and as such action on lime mortar most particularly is very deleterious until the mortar has thoroughly set, and as that process takes a much longer time than with Portland cement mortar; it follows that Portland cement mortar is to be preferred to lime mortar on this ground alone, without enumerating other advantages; but care must be taken that only sufficient cement mortar is mixed for immediate requirements, and on no account must it be re-worked, and it should be used directly it is mixed.

Portland cement mortar used in the proportions of 6 or 7 of sand to 1 of Portland cement, is somewhat harsh, stiff, and raw in working. It is necessary to give

it a free consistency to enable it to be easily manipulated, and to use a small proportion of lime for that purpose, which is to be preferred to loam or very fine sand; but the quantity of lime used should only be sufficient to make the mortar plastic enough for free use. The deteriorating influence of a small mixture of loam is marked in the early stages of the process of induration, but it is believed to decrease considerably when the mortar is thoroughly hard, and after some months have elapsed. If loam is used, it should not be in the form of loamy sand, but the sand should always be clean and sharp, and the loam be added separately. A small mixture of pure clay has been used with cement mortars to mitigate their roughness, and is considered by some better than loam; but, of course, all cement mortars are stronger if not so mixed or adulterated.

It has been proved by the numerous experiments of Mr. Colson at the Portsmouth Dockyard extension works, that a mixture of 4 or 6 parts of sand to 1 of Portland cement produces a mortar far superior to any that can be made with lime, and at slightly less expense; and that as a general result, the adhesive power of mortar, mixed in the proportions of 8 of sand to 1 of cement, with the addition of a small quantity of lime, or yellow loam, to render the mortar more plastic and tenacious, was superior to grey lime mortar mixed in the proportions of 2 of sand to 1 of lime.

Percolation of water through a porous coping stone to lime mortar used in the joints has resulted in displacement of the coping, but it was stopped by the

stone being reset in strong Portland cement mortar. To prevent such percolation, the more impermeable stones, such as granite, and not freestone, should be used, so as not to have to rely upon the impermeability of the joint.

Mr. Colson made a series of experiments to ascertain the comparative strength of grey lime and Portland cement mortar, also Portland cement mortar with the addition of lime and loam. The general results briefly stated were as follows:—The grey lime mortar consisted of 2 of sand to one of lime mixed with $1\frac{1}{3}$ of water, which included that required for slaking the lime; the mean breaking strain was 37 lbs. per square inch. The Portland cement mortar consisted of 6 of sand to 1 of cement mixed with $1\frac{1}{4}$ of water, and 8 to 1, and $1\frac{2}{3}$ water, and 10 to 1, and 2 of water, the breaking strain per square inch in lbs. being respectively 104, 69, and 50 lbs., and the ratios compared with lime mortar 2·81 to 1, 1·86 to 1, and 1·36 to 1. He also experimented upon the relative strength of Portland cement mortar, and Portland cement and lime mortar, and Portland cement and loam mortar, with the following summarised results:—The Portland cement mortar was the same as the before mentioned. Portland cement and lime mortar consisted of 6 of sand to 1 of cement, 0·50 of lime, and $1\frac{1}{2}$ of water, which included that required to slake the lime; 8 of sand, 1 of cement, 0·66 of lime, and 2 of water; 10 of sand, 1 of cement, 0·83 of lime, and $2\frac{1}{2}$ of water. The breaking strains were respectively, per square inch, $73\frac{1}{2}$, 59, and $42\frac{1}{3}$ lbs., and the ratios, compared with *cement*

mortar, 0·70 to 1, 0·85 to 1, and 0·84 to 1; and as compared with *lime* mortar, 2 to 1, 1·60 to 1, and 1·14 to 1. The Portland cement and loam mortar consisted of 6 of sand, 1 of cement, 0·50 of yellow loam, fresh dug and rather damp, and 1 of water; 8 of sand, 1 of cement, 0·66 of yellow loam, and 1·33 water; 10 of sand, 1 of cement, 0·83 of yellow loam, and 2 of water. The breaking strains respectively, per square inch, were 61, $38\frac{1}{2}$, $28\frac{2}{3}$ lbs., and the ratios, compared with *cement* mortar, 0·58 to 1, 0·55 to 1, and 0·57 to 1; and compared with *lime* mortar, 1·64 to 1, 1·04 to 1, and 0·77 to 1. It will be noted that the Portland cement mortar, i. e. simply sand and Portland cement with the addition of lime and loam, loses strength very considerably, and other tests have shown the same results, as might have been expected.

Mr. Bernays, at the Chatham Dockyard works, abandoned ordinary building mortar, and used a mixture of 1 part of cement to 7 parts of coarse, clean, sharp sand, and 1 part of foundry sand, the latter containing about 10 per cent. of loam, or about $1\frac{1}{2}$ per cent. in the mortar ready for use. The loam was added to produce the necessary softness, and for easy working of the mortar.

Messrs. Bazalgette and Grant, in comparing Portland cement mortar with blue lias mortar, added in bulk in the experiments the quantity of lime to make it the same price as a less quantity of Portland cement, with the result that the Portland cement mortar produced much stronger brickwork than by the use of the proportionally increased quantity of lime mortar.

Mr. Baldwin Latham has stated that sewers constructed twenty years have been found with the lime and cement completely washed out, owing to the ammonia, by chemical action, converting the lime into a readily soluble material. Portland cement is better than lime for resisting the chemical action of sewage; lime made from chalk the worst.

An internal ring of brickwork protects the backing of concrete in sewers.

Portland cement and lime concrete, if used for the foundations of machinery, should be protected from oil and grease, as they have a tendency to disintegrate and weaken concretes.

Lime concrete sets much more slowly than Portland cement concrete, which in twenty-four hours is generally sufficiently hard to resist injury from water agitated by ordinary pumping operations. Portland cement concrete should always be used in weeping, or wet foundations; and in thick walls and masses Portland cement or the best hydraulic limes should alone be employed, so as not to have to rely on the carbonic acid in the atmosphere to harden the concrete, for it would then not be properly indurated, being deprived of air. No advantage is gained by using a mixture of lime and cement. Upwards of 500 experiments made by Mr. Grant proved this. In saving cement, it is better to replace the cement taken away by gravel or sand, in preference to an addition of lime.

Lias lime should always be ground to a fine powder, as the quality of the mortar is improved by fine-grinding, and the slaking should take some time

before the other ingredients are added, in order that all the particles may be thoroughly combined with water. When the lime is completely slaked it should be used, as it will then harden better. The reason is considered to be because the hydrated silicates begin to form when the lime is in a pasty condition, and disintegration is prevented. Mr. Wolfe Barry, at the Barry Docks, had the lime soon after being drawn from the kilns completely wetted in sheds, and covered with sand for not less than 7, or more than 14 days before being used.

If lime concrete has to be lowered through water, before commencing the work, experiments should be made to ascertain if it will then harden and properly set, because with inferior hydraulic lime, concrete which would set in a few days if simply deposited into a trench, may not set when it has been lowered through water.

Pure limes mixed with sand and so made into mortar become indurated by combination with the carbonic acid in the atmosphere, or water in which carbonic acid can penetrate, but cements become hard better in water than in air; and while the process of induration of all lime mortar is slow and gradual, cement inherently possesses the power of setting and becoming hard, and only requires the proper quantity of water to be equally and thoroughly mixed with it to make it set, and become thoroughly hard.

Experiments have shown that many months after mixing 2 to 1 lime mortars in masses, the chemical action had only penetrated from $\frac{1}{8}$th to $\frac{3}{16}$ths of an inch,

and although the mass was dry and moderately hard, such state was mainly caused by evaporation of the water, and not from the absorption of carbonic acid. This is another testimony against lime mortars being used in a considerable mass, and shows their inferiority to Portland cement mortars.

At Seacombe Ferry works, on the Mersey, random soft sandstone was adopted, set in hydraulic lime mortar, the stones being large, containing 20 cubic feet each. It was found that with a mortar of 1 of Halkin hydraulic lime to 1·57 parts of sand, the mortar was not sufficiently rich, but when the proportions were 1 of lime to 1·25 of sand, it withstood the action of the tide in unfinished parts much more satisfactorily. Portland cement mortar is to be preferred in such situations, unless there are special reasons to the contrary.

Concrete made of quicklime has a tendency to swell. In summer, this increase has been found to be about one thirty-second, and in winter, about one forty-eighth; but no reliance can be placed upon its swelling as sometimes it does not increase in bulk. Quicklime, if used for concrete, reduces its adhesive powers, and makes it friable, therefore it should not be employed. It dries sooner than slaked lime concrete, and if any particular form is required, quicklime cannot be used.

Mr. Grant's experiments have demonstrated that Roman cement is about two-thirds the price of Portland cement, but that its strength is only one-third; therefore it is about double the cost of Portland cement, if measured by strength.

The "Coignet" artificial stone, or concrete, has been extensively used in France for about thirty years. It consists of a mixture of sand, powdered hydraulic lime, and a percentage of slow-setting cement. The lime and sand are moistened with a very small quantity of water, and after that operation is completed, they are ground to a stiff paste in a mill, and moulded to any desired form. The proportions most generally used are as follows:—500 parts of sand to 100 parts of lime, and 50 or 25 parts of cement. This material has been used with success in France for all kinds of work. Bridges, viaducts, and aqueducts of considerable span and importance have been constructed with it. In this chapter, reliable experiments have been mentioned which showed that no advantage is gained by using a mixture of lime and cement. A cement concrete is therefore to be preferred to one of lime and cement.

Concrete made with lime at Hull Docks, did not withstand the action of running water, small orifices in it soon became enlarged, and the lime was washed away. Portland cement concrete withstood it.

CHAPTER XIV.

PORTLAND CEMENT CONCRETE IN SEA-WATER.

A GENERAL view of the few cases of serious deterioration of concrete deposited in sea-water leads to the conclusion that they appear to have arisen either by unsuitable or unsound Portland cement having been used, that is a Portland cement containing a high or very high percentage of lime or magnesia; from insufficient uniform fineness, so that the setting may be equal and no coarse or insufficiently burnt particles be present to gradually absorb water; from the want of thorough air-slaking, and precautions to ensure that too little water was not used to slake the lime in the cement; from insufficient time being allowed for perfect hydration; from the concrete not being equably and thoroughly mixed; from a badly proportioned, or a too weak mixture, i. e. from too little Portland cement being employed; and because a water and air-tight covering to the mass of concrete was not provided to prevent percolation: but if these matters are properly regarded, and they can be with almost inappreciable expense, there is no reason why Portland cement cannot be employed with the greatest confidence in marine works of every description, and it can be declared that there are no proofs to the contrary, and it may be said that the salts contained in sea-water have no deleterious

effects upon properly proportioned, well mixed Portland cement concrete made from sound and durable cement, nor has it been shown that such concrete will absorb the magnesia contained in sea-water unless it is disintegrated by other means.

Manufacturers are well able to prevent unsoundness or overliming in Portland cement, unless it must stand excessive tensile tests at an early date, and a kind of general invitation is offered to overlime a cement, for the excess of lime alone may be sufficient to disintegrate the concrete without magnesia, and the other necessary operations can be readily effected by due care and attention; but occasionally, as in almost every substance used in construction, failure may happen from causes difficult to ascertain or provide against, but they are very rare indeed; and because steel rails break, bridges fail, buildings collapse, no fear is entertained that the substances generally used and *properly applied* in the constructive arts should be abandoned, for no material can be pronounced absolutely perfect in its present condition; and whereas lives have been lost by the failure of metallic structures and buildings, no instance has occurred in which it has been proved, or even hinted, that a disaster was caused by any failure of Portland cement concrete, whether in structures in sea or fresh water, or on land. The testimony of many years' use under the most varied conditions and circumstances proclaims that Portland cement, properly manufactured and used, is one of the most reliable materials that can be employed in construction.

In order to prevent disintegration it is necessary to ascertain the causes of it, and to examine the reason of any deleterious action. Portland cement can only set and harden by chemical action when water is added to it, and therefore if insufficient water is provided, it cannot possess its full strength, or be quiescent, as unset and unslaked particles will continue to seek for the moisture necessary to produce a state of rest. Provided the magnesia in a Portland cement is of the usual small percentage, i. e. not exceeding 0·90 per cent., expansion to such an extent as to cause disintegration, proceeds from free or caustic lime, i. e. uncombined with any other substance. It can be washed out from concrete in sea-water, and magnesia, devoid of cementitious properties, will take its place, i. e. the salts of magnesia in sea-water will be deposited in porous concrete, but it is not the magnesia alone which is so deposited from the sea-water, that disintegrates a Portland cement, but that which is *in* the Portland cement, and on absorbing water expands, for magnesia in a Portland cement is different to that precipitated by sea-water leakage into concrete, the latter being inert and precipitated as a soft bulky hydrate, for all the salts in sea-water are already hydrated ; such a deposit does not cause expansion, but crystalline compounds may be formed at the same time which do. The magnesia in the Portland cement is only to be feared when it is above prudent limits, but the free lime is the dangerous element; however, as the hydration of lime and of magnesia proceed at different rates, a state of repose is not simultaneously attained in all the constituents of

any Portland cement having an appreciable percentage of magnesia in it. The force of any chemical action, in order to cause disintegration and not a simple failure of cementitious strength, must exceed the cohesion possessed by the mass of concrete, and when that occurs, fracture from expansion happens, and such effects may be more marked at one place than another from inequalities in the character of the concrete, but any expansion tends to produce porosity, and ultimate cleavage, under renewed supplies or pressure of water.

Attention has been directed to the fact that all hydraulic cements with a calcareous basis are completely decomposed by *fresh* water alone, if brought into contact with the water in a sufficiently fine state of subdivision, and that the effect must be greater with water laden with salts. The lime is then completely extracted, leaving only soft, loose hydrates of silica, alumina, and ferric oxide without any cementitious powers.

Dr. Michaëlis, in a paper,* states at length, which is here somewhat abridged, that the main points to be considered in erecting concrete structures in sea-water with the aid of hydraulic cements are :—1. Completely impermeable mixtures, as 2 to 1 of mixed grain, of which at least one-third must be very fine sand; the requisite gravel and ballast being added. This impermeable layer should surround any porous kernel. Iron ties should be introduced where the compact shell and the poorer kernel are joined, and, if possible, they should be made at one operation. 2. Chemically regarded,

* 'Minutes of Proceedings Inst. Civil Engineers,' vol. cvii.

cements or hydraulic limes rich in silica and as poor as possible in alumina and ferric oxide should be used, for aluminate and ferrate of lime are not only decomposed and softened rapidly by sea-water, but they also give rise to the formation of double compounds, which in their turn destroy the cohesion of the mass by producing cracks, fissures, and bulges. The salts contained in sea-water, especially the sulphates, are the most dangerous enemies of hydraulic cements. The lime is either dissolved and carried off by the salts, and the mortar thus loosened, or the sulphuric acid forms with it crystalline compounds, as basic sulphate of lime, alumino-sulphate and ferro-sulphate of lime, which are segregated forcibly in the mortar, together with a large quantity of water of crystallisation, and a consequent increase in volume results. The separation of hydrate of magnesia is only the visible, but completely innocuous, sign of these processes. The magnesia does not in any way enter into an injurious reaction with silica, alumina, or ferric oxide; it is only displaced by the lime from its solution in the shape of a flocculent, slimy hydrate, which may be rather useful in stopping the pores; but can never cause any strain or expansion, even if it subsequently absorbed carbonic acid. The carbonic acid, whether derived from air or water, assists the hydraulic cement as a preservative wherever it comes into contact with the solid mortar. It could only loosen the latter if present in such an excess that bicarbonate of lime might be formed.
3. The use of substances which render the mortar, at any rate in its external layers, denser and more capable of resistance. Such substances are: *a.* Sesquicarbonate

of ammonia, from gas liquor, in all cases where long exposure to the air is impossible. Such a solution, applied with a brush or as a spray and then allowed to dry, converts the hydrate of lime into carbonate of lime. The latter is not acted upon by the neutral sulphates present in sea-water. The texture of otherwise sound cements is not injured by the action of carbonic acid, for it renders them more capable of resistance, except in the above mentioned case, which is extremely rare, when bicarbonate of lime is formed and goes into solution. *b.* Fluosilicates, among which magnesium fluosilicate is most to be recommended. The free lime is converted into calcium fluoride and silicate of lime, and in conjunction with the liberated hydrate of magnesia, these new products close the pores of the mortar. Both salts are sufficiently cheap to be used on a large scale. *c.* Barium chloride. 2 or 3 per cent. of the weight of the cement is dissolved in the water with which the concrete is mixed. This forms perfectly insoluble barium sulphate with the sulphates of the sea-water, while the magnesia remains in solution as magnesium chloride. Although in this case there can be no further closing of the pores, yet the insoluble barium sulphate which is formed affords some protection, and does not give rise to any increase of volume (swelling). From 2 to 3 per cent. of barium chloride does not in any way diminish the strength, as has been proved by means of comparative tests of English and German cements. Frequently the strength of the mortar is increased by this addition. This substance is only to be used in the external, perfectly watertight skin of the concrete; in

other words, in the 4 to 8-inch coating, composed of 1 cement, 1 to 2 sand, and 3 to 4 coarse gravel, flint, broken stone, &c.

If a Portland cement with a high percentage of lime in it must be used in marine, or any work, it should be thoroughly burnt and very finely ground so as to aid the air and water slakings.

Experiments have shown that if Portland cement, supplied to a well drafted specification, be properly gauged, and allowed ample time to set, and then be broken into powder, the cement has much of its lime removed, and it becomes replaced by magnesia, but, if a block is immersed under the same conditions, the surface only is affected, and that *un*importantly if it has set hard; also when any mixture is watertight. It is the action of the sea-water on every particle of the cement in a powdery condition that is to be guarded against, for chemical action is more rapid with a powder than a solid.

An overlimed Portland cement exposed to the wash of sea-water in the open sea, will have some of the uncombined lime removed, and magnesia, &c., will be deposited. The quantity of magnesia contained in sea-water has been estimated as $\frac{1}{500}$th by weight; however, it is not, as it were, a single immersion that is deleterious, but the fresh charges of sea-water that must be excluded, because each by pressure brings fresh supplies of magnesia, hence the importance of impermeability. It is the filtration through and percolation under pressure in a concrete having free lime in it, and not the mere immersion in sea-water that is to be specially

guarded against. In fact, the concrete becomes a subsiding and filtering bed. Theoretically, the full amount of lime which could be chemically combined with the silica should not be exceeded.

The effects of sea-water on concrete have been well summed up almost as follows, that the salts dissolved in sea-water will attack Portland cement in proportion as the cements are poorer in silica and richer in alumina and ferric oxide. Lime is removed, and magnesia is deposited in the mortar as a soft, bulky hydrate. This magnesia *cannot* cause expansion or "blowing," but it has no cementitious properties even when converted into carbonate. Crystalline compounds are formed at the same time which expand and forcibly destroy the cohesion of the mass, already weakened in consequence of the solvent action. Portland cements rich in silica, i. e. not less than about 22 to 25 per cent., and correspondingly poor in alumina and ferric oxide, should be preferred for marine work. Highly silicious cements set slowly, but from the moment of setting they harden with energy, continue to increase in strength for a long time, and finally attain the highest strength. Cements rich in alumina set quickly. The destruction of such cement is not due to added gypsum, but to the sulphuric acid compounds subsequently penetrating the mortar with the sea-water. Sulphur compounds, especially sulphuric acid compounds, when present in too large a quantity, or when they act continuously upon hydraulic cements, destroy these latter irresistibly.

Some French experiments showed that magnesium

sulphate was the injurious substance in sea-water so far as cement was concerned.

With regard to the provision of an impervious face, and the advisable proportions of the ingredients to be used in forming a concrete which will be submerged in sea-water, and be subject to wave action, homogeneous structures with an impervious coating are the best able to resist disintegration, and therefore any concrete that has to withstand water pressure should be as dense as may be economically practicable, and the mass should be entirely enclosed, and in the case of a breakwater or pier not merely on the two sides, but also at the base and top, and particularly at the base, as water may filter through if the foundation is not on impervious ground, which it should be if possible. The deleterious effect of the percolation and flow of sea-water has been explained, and a flow of fresh water is also injurious, for in both cases lime would be extracted, a deposit having no cementitious value be thrown down, and an expanding force may be generated in the mass.

If a properly proportioned concrete is made with excellent Portland cement thoroughly air-slaked, and mixed with sufficient water for perfect setting and hardening, there is no reason to fear, even if water penetrated the interstices of the thoroughly set particles, that it would have a deleterious effect upon it, always provided that it was what may be termed ordinary sea or fresh water, and that the pressure was slight, and that no compression of air or water was caused to break up the mass. It has been occasionally somewhat hastily concluded that because sea-water percolating th.ough

concrete does extract any uncombined lime in the mass, as has been previously explained, that the same action proceeds in the case of all exposed surfaces, such as the face, but this has not been proved, or that the sea-water deteriorates the face by chemical action, and there are proofs to the contrary, not only in the waters of the Northern latitudes, but also in the fact that in the warmer seas and tropical regions sea-weed quickly covers the surface, and remains, which shows the face does not scale or become visibly deteriorated. However, to prevent any such possible deterioration and to reduce any exposed surface to the least area, it should be as even and smooth as possible when the concrete is deposited, and depressions and protuberances should not be allowed, but if a surface has to be patched in order to make a level, smooth face, the face will probably be of unequal strength, and may not have a uniform smooth face until the whole has been carefully coated.

Where tides simultaneously rise or fall on each side of a structure, concrete is not so severely tested, except perhaps between the highest and lowest high-water levels, as when water rises upon one face only; and intermittent immersion appears to have a greater effect on unsound concrete than continual submersion. If porous concrete be exposed to an unbalanced pressure of water, a flow will be created, and the fresh supplies of water cannot improve the concrete, and may probably cause either slight or dangerous disintegration. The places where failures generally occur are between about high and low water, and the mass becomes disintegrated by alternate exposure to air and sea-water.

With regard to the proportions of Portland cement, sand, and gravel or stone, as the ingredients may vary considerably, and the methods of mixing and depositing, degree of exposure, &c., these should be considered in each case, for without similar circumstances and materials the proportions used may not give the same results; for instance, a very finely ground cement would make a more impermeable concrete than an equal quantity of coarsely ground; the character of the sand and stone would also cause a difference, as has been shown in the previous chapters; however, always remembering these governing conditions, it may be stated that there are certain proportions which it is not advisable to exceed in marine work, unless under exceptional conditions. Mr. Messent, in his report on the failure of some portions of the Portland cement concrete used in the Aberdeen graving dock, stated that he found the greatest efficiency and economy is obtained by the Portland cement mortar forming about one-half of the quantity of stones, and when the mixed sand and cement forms about one-third of the whole mixture, the strength depending on the relative proportions of sand and cement. When the sizes of the stones vary so as to fit well in the interstices of the larger, the quantity can be proportionally increased, but the stones must be free from sand, or the mortar is weaker.

Various experience of many years, under different conditions, seems to demonstrate that a greater proportion of sand in a Portland cement mortar in which stones are to be mixed than 2 of clean, sharp sand to

1 of Portland cement, see Chapter VII., should not be adopted. It has been found that a mortar weaker than this is unreliable, and that weeping, leaks, percolation increasing to a flow of water, may be then expected, resulting in deterioration ; and it is too poor for concrete in marine work, and cases have occurred where a 3 of sand to 1 of Portland cement mortar has failed, and a $2\frac{1}{2}$ to 1 also, but a 2 to 1 has succeeded, as all that was required was a larger quantity of Portland cement in the mortar. Although the difference in tensile strength between a 2 of sand to 1 of Portland cement mortar and a 3 to 1 mixture is not so much as that between a 1 to 1 and a 2 to 1, the porosity of the weaker increases rapidly, in fact, the porosity of a 3 to 1 mortar is about 10 times greater than a $1\frac{1}{2}$ to 1 mixture.

In exposed marine work, or in any situation such as dock walls, especially graving docks, canal locks, reservoirs, gasometers, or in similarly tried structures, it is not advisable to use a poorer mortar than $1\frac{1}{2}$ sand to 1 of Portland cement. In thick work, a sufficiently thick facing can, perhaps, only be used of such mortar ; in thin work or walls the mortar in the whole mass should preferably be of no poorer mixture. The size of the stone used for such impermeable concrete in an exposed marine situation is of importance, for large stones, which are sometimes usefully employed as ties in a mass, require to be bedded in mortar, or their surfaces may not be covered, and vacuities will occur. In order to ensure that they are thoroughly bedded in the mass of finer concrete and not in contact,

they should only be introduced at intervals, or there will be inequalities in the work, and although the object of using them is to bind a mass together, the effect would be that of causing vacuities, separating the concrete, and offering a channel for a flow of water. Small clean washed stones of the character described in Chapter VI. are to be preferred to large stones. A very dense concrete can be made when the stones are not larger than will pass through a sieve having half-an-inch openings, and for *thick* facework this size should not be exceeded. For *thin* facework, no stones should be used. In general work in the sea, it is not advisable that the stones should be larger than will pass through a $2\frac{1}{2}$-inch sieve, or be less than will be retained on a $\frac{1}{4}$-inch sieve, because then they would approach the nature of very coarse sand. The situation and circumstances must govern the size, but $2\frac{1}{2}$-inch stones are quite large enough, and a more homogeneous concrete is obtained with smaller stones. In an experiment in Shields harbour, Mr. Messent immersed some briquettes for 87 hours in a depth of 18 feet of water, giving a pressure on the briquettes of cement and cement mortar of 8 lbs. per square inch, and so arranged that the water pressure was brought upon the briquettes, and measured, if any percolated. Ninety-four ounces of water passed through the 1 of Portland cement to 3 of sand mixture, and only 1 ounce through the neat Portland cement. This shows the great difference in porosity, and the necessity of preventing by an impervious coating, sea-water, and especially fresh supplies of it, penetrating

into a mass of concrete, as by repeated absorption or drying, the solids contained in sea-water may be left in the mass, and then deterioration follows, if there are any unset particles, and unsoundness in the concrete.

When water-pressure is generally balanced, as in breakwaters, any deterioration caused by percolation is slower, but where it is unbalanced, the percolation and constant renewal of the sea-water will produce a more rapid deteriorating influence, as it will be comparatively fresh, especially within the limits of tidal range or wave action, but if the water is still, the balanced state will lessen the supply of the injurious elements in the sea-water.

CHAPTER XV.

THE DEPOSITING IN SITÛ SYSTEM.

Introduction—Adaptability—Loss of cement—Importance of impervious face—Preparing foundations—Panelling and framing—Fixing piles in concrete mounds instead of driving them—Design of work—Kinipple's system of construction.

One of the cheapest and most expeditious systems of concrete construction, especially applicable to comparatively quiet waters, and for moderate depths, and on a firm foundation, natural or artificial, is the depositing it in a plastic or freshly mixed state *in sitû*, between or against framing, as no expensive or special plant is necessary, and the cost of moving blocks from the sheds to the site and setting them by divers is saved.

Experience of the last few years has forcibly demonstrated that the face of all concrete work exposed to sea-water should be especially hard. It may therefore be advisable to pack durable flat stones into the face concrete, but it is to be preferred if the facing consists of concrete blocks, i. e. properly set without exposure to the sea-water or a flow.

Provided concrete is protected from currents or waves, or motion of water during deposition, in order that no cement may be washed away, it is an advantage

that cement concrete should be covered by water when it is deposited, and no Portland cement sets better than that immersed almost directly after it is in place, as the process of induration proceeds without the loss of moisture which occurs in concrete setting in the air. In all plastic or freshly mixed concrete lowered through water, there is a not inconsiderable waste of cement by it being washed out, varying in amount from about 10 to 20 per cent., and an allowance should be made to counteract it; but this loss may be lessened by careful deposition, and to obviate the reduction in strength, sometimes lengths of breakwaters are so constructed from about low-water level that the work is carried up in lengths faster than the tide rises, no water being allowed to flow over the concrete. There is no doubt, however, that concrete that has to be lowered through water, unless completely protected from any wash, is not so strong as that which is set without being deposited through water when in a freshly mixed condition. Such loss of strength has been roundly estimated at from 60 to 70 per cent. If desired, quick-setting cement can be used for work below low water, and slower setting for that above. An addition of a small quantity of quick-setting cement immediately before deposition assists the concrete to resist currents of water, or wave action, but it has been found that any rich facing put on before the mass has set is liable to be washed into it. In order to consolidate the concrete, it has been carefully levelled and trodden down by divers.

The successful application of this system principally

depends upon the excellence of the Portland cement, its proper proportioning and mixing, absence of a current, and careful and uniform deposition, i. e. as it were, laying it, and not casting it, upon the site. If the deposition is performed in a sudden or ungentle manner some of the finer cement will be disturbed, and a creamy substance will be deposited, and cause inequalities in strength. If the concrete is deposited between frames, the substance will remain, and, as it does not set, it is useless; a slight current, however, will remove it. Consequent upon variation in the character, setting properties, and nature of the aggregates, the time after mixing at which the Portland cement is sufficiently set to prevent its being eroded, and yet not to deleteriously affect the setting powers will necessarily not be the same; in any case a very finely and equally ground cement is required. Concrete deposited *in sitû* alternately exposed to water and air is very severely tested, and its use may be considered as declining in favour of more protected methods of construction, such as the block, with joints of cement grout poured into grooves, projections, and the joints, and so arranged that all the blocks are joined together; or sack-blocks, or concrete in bags.

Some systems of construction for submerged, or partly submerged works are :—

1. The depositing *in sitû* freshly mixed, or plastic concrete.

2. By depositing concrete placed in a bag or sack.

3. (*a*) The small concrete block system, blocks that can be deposited with ordinary lifting tackle.

(*b*) The large concrete block system, blocks requiring powerful lifting machinery to deposit them.

(*c*) The concrete block system, when special lifting plant must be used, and a wall length is deposited *en bloc*, as at Dublin, where a 5000 cubic feet block, weighing 350 tons, was put into place at one operation.

Note.—Although it may be cheaper to make large blocks than small ones, the expense of the machinery for moving and lowering them is an item which frequently neutralises the lesser cost of constructing large blocks.

4. The construction of quay and harbour walls, piers and abutments of river bridges, in loose soil by means of concrete cylinders, by preference placed upon the cutting ring on land before deposition.

5. By the employment of thin hollow cylinders sufficiently buoyant to float when water-sealed, by towing them to the site, sinking them by gently letting in the water, and depositing concrete in the still water in the interior of the cylinder.

Another method of construction is that adopted by Mr. Kinipple, and consists of concrete caissons, made on land, for forming the facings of a pier to a few feet above low-water level, in order to obtain the advantage that accrues to the block system, instead of the disadvantages of deposition *in sitû*, as the block system very seldom fails. In shape the caisson is similar to a channel iron laid on its back, with the legs slightly bent inwards. Another system used by Mr. Kinipple is that of dove-tailed blocks, backed with concrete, to prevent the wash of the waves on concrete deposited *in*

sitû, and thus dispensing with framing and moulds on the site of a breakwater or pier.

All concrete work exposed to the waves should be faced with an impervious mixture of Portland cement and sand, a strong, durable, and non-porous face being of the greatest importance; and, in selecting the stone or gravel, it should not be forgotten that stone, if quickly disintegrated by the sea when unattached to Portland cement, will also weather and waste away when bedded in cement; and that, as soon as such action commences, it is merely a question of time before the whole mass becomes disunited and unstable, for the stone will be separated from the cement.

No open joints, cracks, or fissures, should be allowed in any work exposed to the waves, more especially within the limits of the greatest action, which, for this purpose, may be considered as a few feet below low-water level to a few feet above high-water level, and especially at or about low-water level; as both water and air penetrate therein and become compressed by the impinging force of the waves, and have great powers of propulsion which may seriously affect the work on the unexposed side. If the waves are 3 feet in height, they are, unaided by a current, quite sufficient to wash out the cement to an injurious extent. To lessen the chance of cracks or fissures in long concrete walls, it is well if they are constructed in lengths not exceeding about 40 feet, but care must be taken to connect the set work with that newly deposited.

Unless there are cogent reasons to the contrary, such as the exposed position of the works, the depositing

plastic or freshly mixed concrete *in sitû*, or the bag system in combination therewith, may be used in preference to the other plans; the joints being good, and if proper precautions are taken, this method of construction is sufficiently strong and more economical, always provided the water is not so disturbed as to interfere with the process of setting.

From low-water level the depositing *in sitû* system can generally be used in ordinarily exposed situations, if the timber framework is carefully designed, and well covered with jute cloth; and the bag system can be applied from the foundations to a few feet below the level of low water, except in light sandy soils, or bad bearing strata, when the weight must be more equally distributed over the whole area of the foundation courses, or the bags may sink into the ground, and the work settle unequally. If it does, the whole of the structure may be seriously affected, and a superstructure of plastic concrete above low water, which when set acts as one block, placed upon a dry rubble mound, or on dry blocks deposited upon the bed of the sea, is always liable to settle, as either of the latter artificial foundations may subside, and while some portion may have to sustain the weight of the superstructure, other parts, having subsided, are free from any load, and can be readily displaced by the sea, even if some feet below low water, for a ground swell is even more effective than ordinary waves. The danger of subsidence of such an artificial foundation is that the upper structure may crack, and be shattered in sections, until a breach is made, whereas the aim should be to make a pier a

monolithic mass from base to top, to secure it against scour, and to place it on an immovable foundation.

Mr. Carey, M. Inst. C.E., as Engineer-in-Chief of the La Guaira Harbour Works, Venezuela, successfully completed in 1891, adopted a system of depositing concrete *in sitû*, he having also partly used it in the foundations of Newhaven Harbour Breakwater, of concrete deposited in sacking, which, while sufficiently keeping the concrete in shape, also protects it from erosive action while the cement is in an unset condition. The breakwater was almost entirely constructed in sack blocks. The lower tiers of 160 tons weight were carried to about 18 feet below water level, and from that level to about 12 feet below water level blocks of 130 tons weight were used; there being no tide, a special tipping box was devised by Messrs. Punchard & Co., the contractors, and sack blocks of 70 tons were tipped on the top of the mound, as already described, to about 3 feet above water level. A capping and parapet in mass concrete completed the section. The extreme depth of water was 46 feet, and the total maximum height of the structure about 65 feet.

The surface of the ground upon which the concrete is to rest should not be inclined in one direction transversely, but should preferentially slightly dip from both faces inwards; and if level, it is desirable at each face to dredge or excavate the foundation for about a foot to form a trench, in order that the base may be below the general level, to prevent any chance of sliding action; if this cannot be done, a toe of concrete should be deposited on each side. The longitudinal

bed should be made level in steps, and the ground previously dredged or cleared by divers of all *débris* and loose material, for an immovable foundation is of the utmost importance.

The dredging for foundations, if done by a bucket or grab, worked by a crane on a barge, is economical, because the crane can be afterwards used for lowering the skips, bags, or blocks of concrete.

In estuaries, it may be necessary to cover the foundations with jute canvas lining before depositing the concrete if the water is muddy or has much matter in suspension, to prevent the concrete being damaged.

Where there is a change in the nature of the soil, as clay with rock, or sand and shingle with rock, or sand and shingle with clay, at the point of junction of the different strata unequal settlement may be expected, and the ground for some distance on each side of the alteration in the character of the foundations should be artificially protected, to prevent scour of the waves and probable breach in the work; and it may be necessary to protect the whole area of the softer soil.

The necessary examination and preparation of the foundations having been effected, the erection of the staging and framing can be undertaken.

Should the ground be rock upon which it is proposed to erect a concrete structure deposited *in sitû* between frames, the uprights, or masts, forming the pile supports to the staging can be, if desired, of iron, the ends having the form of a sole plate, a hole being previously drilled in the rock to receive a 2-inch or 3-inch pin passing through the sole plate, and firmly fixed in the

ground; or timber piles can be placed in a disc, and be fixed by divers in the rock as previously described; another method is subsequently mentioned as having been adopted at Wicklow Harbour.

The frames can also be constructed of posts having grooves, into them panels slide, they are tied together with $\frac{3}{4}$-inch or 1-inch tie-rods, which can be built in, if desired. In all cases and systems the framework should be made of pieces of such size that men can handle them, and the usual dimensions of iron and timber should, if possible, be employed.

Among the objections to timber framing for setting concrete *in sitû* are the difficulty of keeping the joints of the planking sufficiently tight to prevent any cement running out, or the ingression of any water, and any movement or shaking, or vibration of the moulds against which the concrete is deposited.

In adopting the ordinary method of constructing concrete works by means of the depositing *in sitû* system, it is necessary to have framework and planking, in order that the plastic concrete may be retained in the form required and the cement not be washed out.

Perhaps it is better to erect a couple of whole baulks at intervals of about 30 or 40 feet, the distance being that of the working lengths, and at distances of 6 or 7 feet intermediate single posts, than have all single posts, or all double posts at wider distances apart; the chief point to attain is to give equal support to the planking. As the framework is practically a cofferdam, but free from any great pressure from a head of water, the established principles of cofferdam con-

struction should be followed, although there is no puddle, and the objection to through bolts, a most important one in cofferdams, does not apply, for they are a necessity in ordinary framework for depositing concrete *in sitû* on a large scale. The bolts can be drawn after the concrete is consolidated, and to enable this to be done, timber trunking should be placed over them before the concrete is deposited. At low-water mark, ordinary cofferdam half-baulk, or double plank outside walings, should be inserted about 10 feet apart, but closer within the limits of wave action. No inside walings should be adopted, as they make recesses in the wall unless left in the work, which is unadvisable.

The planking can be of the ordinary dimensions, 3 inches or 4 inches in thickness, or battens of $2\frac{1}{2}$ inches in thickness, but, unless the height of the work is very small, and there are numerous temporary shores which can be erected if the foundation is rock, or very cohesive, and the wave action merely nominal, or the piling or masts to support the planking at frequent intervals, $2\frac{1}{2}$ inches is the least thickness of the planking that it is advisable to use. Care should be taken that there are no apertures, knot holes, or open joints in the planking, or the water may spurt and wash out the cement and cause holes in the concrete.

About $\frac{3}{4}$ inch in diameter tie-rods, which pass through the work from side upright pile to side upright pile, can be put in, some 6 feet apart in the height of the pile, with the usual nuts, washers, and timber cleats to prevent the bolt ends from being damaged. A tie-rod should also be placed as near the bottom as possible,

and there should be rods at more frequent intervals within the limits of wave action, i. e. from a few feet below the level of low water to the top of the framework. The piles can also be tied diagonally on the face by bars or strips, which is a good plan. When the bolts are withdrawn from the trunking, the holes should be most carefully closed on each side with neat cement, or strong cement mortar, rather quick-setting, and the hole should be filled throughout its length.

For work of very large dimensions, of course, the timber uprights and walings must be increased in strength and number, and sometimes the main piles are made more secure by a little concrete being deposited round them at the foundation level.

The planking beneath low-water mark must be either fixed by divers, or made to slide down between two piles, which is not an easy operation unless the piles are vertical and regular, and it necessitates recesses being filled in when the main uprights are cut off, if the face must be even, or the piles being left in. The framework can be built up *pari passu* with the concrete, and the method of building the panelling will be governed by local conditions; the principal difficulties of exposed timber framework in the sea are to prevent it being washed down and lifted. Loading with old rails, or iron, is frequently adopted to remedy this tendency. The frames should be so arranged that, by inserting temporary cross planks, a length at any point can be made like a box, which protects the concrete from the wash of the tide and wave action. The timber casing should be lined with strong jute, or sail

cloth, nailed to the planking to prevent the sea washing out the cement.

It is obvious that much ingenuity can be exercised in designing the framing, and there is almost no limit to its form and general design. Movable shields of timber, or preferably of iron, because it will not float, can be used.

For quay or harbour walls, of course, the piles and framework can be of much less strength than for breakwaters or exposed sea works.

In exposed situations, as the staging piles by themselves will usually withstand storms, it may be advisable to make the planking removable so that it can be taken away on a storm approaching, and the piles be thereby saved from extra strain, which may cause them to be destroyed.

With regard to the working length of a structure it should not be greater than can be evenly raised, and its extent principally depends upon the rate of mixing of the concrete and its delivery and deposition on the site. 16 to 40 feet is a range of length frequently used.

It is well if the frames are not removed for about three weeks after the deposition of freshly mixed concrete *in sitû.* There should always be a duplicate set of planks, as the removing and refixing of the frames takes a considerable time; the framing should, therefore, be designed, in order that it may be expeditiously removed and re-erected. If desirable, the panelling can extend in sections of the height of the wall instead of over the whole face.

The permanent work may be so designed that it can support the temporary framing without piles. The central portion of a pier being first deposited by the aid of skips, or from a barge, the panelling, to enable the face on each side to be erected, can be made by means of bars or other connections attached to it, thus dispensing with the face piling. This system, however, may require a richer concrete for the hearting of a pier than would otherwise be necessary, and it may resolve itself into a question of saving in the cost of the panelling, facility of erection, expedition of the work, reduction of exposure and increased strength of the framing, as against the extra cost of the stronger concrete.

To obviate the necessity of driving piles for the panelling, the system of making a mound or toe of concrete for the pile to rest in has been used by Mr. Strype, M. Inst. C.E., at Wicklow Harbour, with success, the pile being placed therein before the concrete is set. The mounds can be about four or five feet in height. An application of this system, by which no panelling is required below low-water level, is as follows:—Two trenches are dredged or excavated, one on each face of the pier; concrete is then lowered by means of skips, or self-discharging boxes, holding 20 to 27 cubic feet, directed by a diver until a mound of concrete is formed on each side, reaching to low-water level, piles being fixed in the mounds, which are deposited at intervals along the length of the proposed structure; the slope of the concrete is usually about 1 to 1, or an angle of 45°. The toes or shoes of concrete

will become in a few days sufficiently hard to secure the piles.

The panelling for a short length can be securely fixed to a portion of the structure already finished, and be made to project sufficiently for a few feet of the pier to be completed, and it can be removed when the concrete has set, and be used for the next division of the work. At Colombo Harbour works the pierhead was erected by depositing plastic concrete inside a circular wrought-iron tank or cylinder of $\frac{1}{4}$-inch plates, stiffened and braced by T and angle irons. It was floated out and sunk on the site and then filled with concrete.

In designing a pier, breakwater, or wall, the method of construction, the framework, and panelling required, and the protection that can be afforded against storms, should be considered simultaneously with the laws governing the proper form of the structure, which latter do not come within the scope of these notes; however, it may be stated that the heaviest materials should be placed within the limits of wave action, and projections should be avoided; and it should be borne in mind that waves will glide over a smooth surface without injuring it, but may loosen an irregular face; and care must be taken that waves striking against the panelling do not fall or become driven by the wind, so that they drop upon the top of the work between the panelling. The greatest disturbance may be expected about and above low-water mark, therefore it is advisable to have the planking and panelling made more secure from a few feet below

that level and above low-water mark. Rubble stone mounds, which may be stable a few feet below low-water level, may be disturbed by the first storm, if placed above that height of water. These points should be remembered in designing and protecting staging and panelling against the sea, which has been known to have a force in the highest waves in a storm of upwards of $3\frac{1}{2}$ tons per square foot, although the average force in summer and winter may not be above about one-tenth, or one-third, respectively of the storm power.

The latter part of a gale or storm, i.e. when the wind commences to moderate, is generally the most destructive to works, as the waves become more solid, and have greater impactive force than when they are broken, thinner, and lighter.

It is impossible to compare structures differently situated, whether as regards stability, adaptability, the method of construction, or the cost. The depth of the water is most important, as it chiefly governs the force of the waves; the fetch of the sea, and degree of general exposure, and the intensity and direction of the prevailing winds, and many other local circumstances, must be duly considered. It may be advisable to graduate the strength of a pier according to the degree of exposure, instead of making it of equal strength. Breakwaters formed solid throughout are obviously stronger than if made of face walls of large blocks, or deposited *in sitû* concrete, and the hearting of rubble set in cement, or weaker concrete; or if a monolithic mass is placed upon a rubble mound.

The situation of a structure may be so exposed that no setting operations may be possible at certain seasons, which may mean six months of the year; if then any but the block system is adopted there may be nothing for the men to do until the setting season returns, unless there is sheltered work to construct. In very exposed places, as a general rule, the block system is the best to adopt, as the concrete is set before it is lowered through the water, and the only chance of failure is reduced, in a correctly designed breakwater, to one of defective deposition and joints.

In all exposed works situated upon sand or movable soil, it is necessary to have a platform of rubble random work, or an apron of concrete in bags in front of the pier, on each side, to prevent the waves undermining the structure, the width of the platform being dependent upon the degree of exposure. Flat bags of concrete, containing from ten to fifty tons of concrete, laid upon the top of the berm of a rubble mound, and over its slopes and toes, have been found to effectually protect it from the wash of the sea.

It is of the greatest importance to exclude the air from any structure exposed to the sea, as by wave action it may become compressed and blow out the work; and that the concrete on the face of the wall should not be porous, as the compressed air and the hydraulic pressure created by wave action, will quickly disintegrate it and cause the face to scale. In exceptional cases it may be advisable to coat the pier with a facing of granite.

In comparatively sheltered places, piers have been constructed of two retaining walls, one on each face; the sea side having a parapet, the hearting being of broken rock and gravel deposited in layers between the walls, thoroughly punned and consolidated by the traffic over it in proceeding with the works. The roadway covering should be very carefully made, and should not be less than about 2 feet in thickness. In order to prevent any percolation of water, in adopting this bi-wall system with a central hearting, at the foundation level it is well to extend the concrete across the whole section of the pier, so as to tie and strut the base of the walls together; and the thickness of this foundation course should be not less than 3 or 4 feet, depending upon the width of the structure; and the upper surface of this foundation course should be sloped on each side against the wall, and there should be a solid concrete coping at the top, extending the whole width of the pier, thus making the cross section box-shaped.

In sheltered places, and on the unexposed harbour side of a breakwater, arches can be turned from about low-water level, their width not being greater than about one-third of the cross section of the pier, and the intrados of the archwork being a few feet below high-water level. To prevent small vessels becoming held by the arches, a floating boom can be attached to the face of the archwork.

In all cases, especially on a shingly coast, it is necessary that the faces of a pier be able to withstand the attrition of shifting shingle or sand, which

will abrade its surface exposed to the sea; and the face concrete must, therefore, be richer in cement than the hearting.

It has been found that ships rubbing against a wall of concrete do not injure it if the face is of strong concrete, but that the square, blunt, iron-edged bows of barges gradually wear holes in it. It may, therefore, be necessary to place fenders in the work to protect it.

Mr. Kinipple, at Quebec Harbour, deposited crib-work filled with plastic concrete partially set, it being floated out, and sunk on bearing piles. He has also shown, on a large scale, that plastic concrete, deposited in separate masses, becomes sufficiently set to be able to resist the action of a current of water, so that the cement is not washed out, and that it unites with other pieces when submerged.

His patented monolithic system of forming break-waters, sea-walls, and similar structures, which has been successfully adopted, consists in forming joint-less masses of concrete *in sitû*, neither divers, staging, overhead travellers, nor other particular plant being required. The concrete is mixed either in bulk or block, and allowed to partly set or harden out of water, so that when thrown overboard into the foundations, or work, it is sufficiently hard to prevent the cement separating from the sand and shingle while being lowered through the water, and is yet soft enough when deposited to fall together and form a compact structure equal in strength to the hardest rock. This system has been adopted, when the con-

crete was deposited at the back of sheet piling in depths up to 38 feet, behind small dovetailed blocks of concrete, and for a groyne when sheltered by a movable wrought-iron shield. If sea-walls are required to be built with a straight or curved face, iron rods are fixed in the foundation, between which planks slide, which keep the concrete in the desired position for a few days until it is set and becomes hard.

This system is an important modification of the depositing *in sitû* method of construction, and, therefore, particular reference is made to it; perhaps the only demurs that may be urged against it are, that the disturbance of the mass *after* the process of setting has proceeded for some time weakens the concrete, see Chapter V., "The Setting of Portland Cements," that depositing an unset mass in such an unprotected way results in a loss of cement and disturbance of the lump, and that, if the concrete is not deposited until nearly set it will not reunite. On the other hand, experiments by Mr. Kinipple, at Garvel Park Dock works, Greenock, with a $3\frac{1}{2}$ to 1 concrete showed that if 8 hours in the air only elapse between mixing and deposition, the strength is not affected, but it then diminishes, and at eighteen hours it is about one-half the original strength, and that if rammed into moulds it will form a monolithic mass. A mixture of $3\frac{1}{2}$ of sand and ballast to 1 of Portland cement was left three hours to set, and a 6 to 1 concrete five hours, before being deposited. The best results were obtained when the concrete was mixed with the minimum quan-

tity of water and rammed into boxes immediately on mixing operations being completed, and deposited when in a state approaching the solidity of stiff clay.

In Chapter VII., "Proportions of the Ingredients," the proportioning is generally considered. Concrete to be deposited in an unset condition through water should obviously be richer than when it sets on land, as in the latter case it is known no cement can be washed out. About 4 to 1 in a moderately exposed situation is as weak a mixture as desirable, i. e. say 3 or 4 of stones set in a 1 of sand to 1 of Portland cement mortar. In a sheltered situation there might be 5 of stones. The stones to easily pass through a $2\frac{1}{2}$-inch mesh, and to be retained on a $\frac{1}{2}$-inch mesh.

CHAPTER XVI.

LOWERING THROUGH WATER FRESHLY-MIXED OR PLASTIC CONCRETE, AND CONCRETE BLOCKS.

Necessary precautions—Some different systems, &c.

WATER must not be allowed to percolate through plastic or freshly mixed concrete, and it should be at the head level to prevent any local flow, and to ensure that the concrete is deposited in still water instead of in a current. If calm water is impracticable the concrete should be made richer than would otherwise be necessary, so as to provide for some of the cement being washed out and lost. Concrete of the usual proportions will generally be secure against the action of moderate seas, after it has been deposited for twenty-four hours ; but a practical test should be made in each case.

In a river, by temporarily enclosing the site of the structure, so as to prevent the action of the current being felt within it, but not with the object of keeping out still water, concrete can be, and has been, deposited through great depths of water, such as 50 to 70 feet, with complete success.

In tide work, when the concrete is in place, it should be carefully protected by means of a covering, if feasible; and as in almost all tidal rivers there is a deposit at

each tide, it is necessary, in order to ensure a perfect joint, and sound work, that such deposit should be removed either by flushing, brushing, or scraping, before any fresh concrete is added.

To prevent the cement being expelled from the concrete, thick canvas sail, or gunny bag jute cloth, or tarpaulin, is a simple and good protection; if that is not available, planking laid on the work affords a partial guard, but all covering material must be weighted.

Care should be taken that uprising, or falling water caused by tidal action, however calmly, does not wash out any cement, and that the concrete is thoroughly mixed, and that in lowering it in skips, bags, or other apparatus, it is not jerked and shaken about so as to cause the aggregates to sink to the bottom; as should such action be created there will be veins and layers of unequal consistency and strength.

The methods employed for lowering and depositing concrete are numerous, and such machinery can be arranged with a single movement backwards or forwards, and lifting and lowering motion, or so as to radiate or entirely revolve. In these notes only a few systems can be mentioned, but full information can be found in a paper read on the 7th March, 1893, at the Inst. C.E., by Mr. Walter Pitt, M. Inst. C.E., on 'Plant for Harbour and Sea Works.' Not one is universally, economically, or practically applicable. Some systems, such as lowering concrete from a hopper barge, are only fit for sheltered places, or for calm weather. Plastic or freshly mixed concrete can be

filled into frames by means of skips lifted and lowered by a crane on an overhead traveller, if the staging is sufficiently strong, and thus be deposited in comparatively still water; or can be put in place by a projecting crane, or other simple lifting, lowering, and self-discharging apparatus, which should lower and deposit the concrete gently and slowly; and in designing a crane for depositing skips, the jib should be sufficiently high that the parapet can be erected with it between frames; the top of the parapet may, perhaps, be as high as 20 feet above the level of the roadway of the pier.

In lowering or raising concrete blocks, the ordinary "lewis" system, although the most convenient, is seldom used, as it is found that the lewises frequently split the blocks at the holes owing to insufficient bearing area; but blocks are often lowered by outside claws, or simple chain attachment. Pear-shaped, or oblong holes are also formed in the concrete blocks by moulds during the operation of making the block, which are removed upon its having set. An iron bar is passed through the hole having a T or other unequally shaped end, and is turned until the end of the bar interlocks with the under side of the block, it being returned and disengaged upon the block being bedded.

Very heavy blocks have been deposited by floating shears on an iron barge worked by steam. Mr. B. B. Stoney, at Dublin Harbour works, lifted and lowered blocks by such means, weighing 350 tons, of the following dimensions, 27 feet in height, 21 feet 4 inches in width, and 12 feet in length, making the

same length of quay. Such a system requires special and costly plant, and is only justifiable under the circumstances of such a particular case as at Dublin.

It has been found that when concrete is deposited in a freshly mixed state in self-acting boxes, it should be in a considerable quantity, and not less than about two cubic yards, as the increased weight produces greater cohesiveness of the material, lessens the effect of the cement being washed out, and the finer particles of the cement being separated from the coarser, i. e. the chalky ingredients from the clayey, &c. The concrete can be well pressed into the boxes, if thought desirable.

Concrete can be deposited by means of box shoots with valves, and skips are sometimes lowered to divers and are not opened or released until their correct position is indicated. The bottom of large skips usually opens on hinges, the hook which holds them being released by a trigger. If the skip is very large, counterbalancing weights are attached to assist the closing of the doors. Self-acting skips have been used holding as much as 15 cubic yards of concrete. Another arrangement of skip is that in which it is suspended from a self-disengaging claw, so contrived that the contents of the skip cannot be discharged until the bottom is reached. The boxes, skips, or bags should not be lowered very quickly, in order to allow time for the air in the concrete to escape, and gentle deposition is important in order that the loss of cement on first contact with the water may be reduced to a minimum.

Concrete can also be deposited by means of jute gunny bags, or sacking, which open on reaching the work, and can be manipulated by ropes, pulleys, or other usual lowering and raising apparatus, the bag being withdrawn when opened, provided there is no current or wave action to wash out the cement, or precautions must be taken, such as temporarily covering it, or not expelling the contents of the bag until they are partially set, and able to resist a flow of water. The time required for concrete to attain such a state can be ascertained by experiment, and it can then be filled into the bags a few minutes before such a condition is approached; but as it more or less disturbs the process of setting, it is not to be particularly recommended. Iron or wooden skips, or boxes, are better than bags for depositing concrete.

In rough water and an exposed situation, where it is impossible to lower blocks of concrete by aid of a floating stage, instead of an overhead gantry, a "titan," or projecting jib, is frequently used, running on rails laid upon that part of the work which is finished. The "titan" should be taken to a sheltered position when the day's work is done, and should be constructed to run backwards or forwards; but if the blocks are of average size an ordinary steam travelling crane can be used.

It is sometimes necessary that the work should be executed very quickly. If such be the case, it can be expedited by erecting a staging, because the "titan" can only be used as the permanent work is finished, as it must travel over it. The relative advantages of the

"titan" and fixed staging systems should be fully considered before deciding upon the method of deposition. If the cost and the time required for execution be found to be nearly identical, the land method of deposition is to be preferred to the floating system.

At Trieste, concrete was deposited through spouts, the bottom of the latter being fixed in a casing of the form of the pier made of planks attached to piles. The depth of the water was forty feet. The deposition of the concrete through the spouts was continued until it reached the surface of the water.

In depositing concrete through spouts there is great risk that the aggregates will become separated from the cement. The chief object to be desired in lowering freshly mixed or plastic concrete through water is to prevent any disturbance of the mass, and to deposit it in the work in the same thoroughly incorporated condition it possessed when the operation of mixing was completed; therefore the simple spout system is not a good plan, but a modification of it could be made in the following manner:—A light iron or timber cylinder made in lengths, with easily fixed joints, reaching from the stage upon which the concrete is mixed to a distance of about two feet from the bottom, with claws for it to rest thereon, could be used, inside which can be an adaptation of the system of the endless bucket dredger, with movable flags, the concrete being simply placed in the bucket or buckets at the top on the flaps being lifted, and the discharge taking place in the usual manner by tipping, thus combining the advantage of protection afforded by the spout system without mate-

rially disturbing the concrete after it has been mixed. The buckets should be as large as possible, and at wide intervals. The lower end of the cylinder and bucket dredger could be moved, raised, or lowered, by a chain attached to a crane. A diver, with whom communication should be made by a speaking-tube instead of life-lines, would guide the bottom of the apparatus, and see that it discharged the concrete, and the buckets could be fed direct from the mixing stage.

CHAPTER XVII.

THE BLOCK SYSTEM.

Adaptability—Making the blocks—Bond—Joints of blocks—Importance of solid top course, &c.

The concrete block system in an open sea and exposed coast is to be preferred to the depositing *in sitû*, or bag-work methods of construction, as there is no uncertainty about the strength and general quality of the blocks, for they are seen before deposition; but the contents of bags may be disturbed and uneven in strength; and, with regard to concrete lowered through water, it may not be of equal consistency.

Blocks of concrete can be made to dimensions by pressing or ramming the materials into moulds, which can generally be removed from twenty-four to forty-eight hours after they are filled. To prevent adhesion of the concrete to the moulds, they can be covered with a thin coating of petroleum, soap, or whitewash, &c., but care should be taken that no substances are worked into the concrete, or they may deleteriously affect it.

The blocks can also be made in moulds simply by placing rectangular sand-bags one upon another until the required dimensions are reached. The mound so constructed must be lined with sail-cloth, which must

extend sufficiently to fold over the top of the concrete when it is at the right height, and then be weighted down. The concrete having had time to set, the bags are removed, and the sailcloth taken away. It is obvious that the side of any block can be used for the face mould for another block to which it will become attached; but, of course, timber moulds are to be preferred, and the blocks are better shaped and the joints superior.

When concrete has to be made in very large masses, an additional quantity of cement should be used to that for blocks of ordinary dimensions. Care should be taken that the blocks have had ample time to set before being deposited; if not, they will be damaged by a current of water or the wash of the sea; and as concrete blocks do not usually harden so well in dry air, when exposed to the rays of the sun, as in water, it is not advisable to deposit them before from fourteen to twenty-eight days after being made, the time varying with the size. In hot climates the blocks should be watered or kept in a damp state for a few days after being formed, so as to keep them moist for equal and proper setting. Blocks of about 15 to 20 cubic yards will generally set in a month or six weeks, but the upper blocks should be allowed to set for a longer time, say about two months, before being deposited, as they may have to bear heavy loads from cranes, a "titan," which may weigh from 150 to 300 tons, or other machinery, directly they are put in place, and may crack. A settlement will generally be caused, but if the blocks are properly made, set, and deposited, and

the foundations secure, it will usually not exceed from 3 to 6 inches.

Mr. Grant's experiments showed that if the quantity of cement is less that 1 to 2 or 1 to 3 of the aggregates, the blocks should be kept some time out of water in a damp place, and be allowed to harden before being used, and that in making blocks of Portland cement concrete it is desirable to occupy no longer time than is necessary to effect a thorough admixture of the cement with the sand and gravel.

There is a limit to the economical size of the blocks, which, to a great extent, is regulated by the plant and the facilities at hand for handling, moving, and depositing them on the site; and the blocks should not be made too large for cohesion of the material. For sea work it may be important to have blocks of very large size, but they are most difficult to deposit from a floating stage in an exposed situation; but blocks that have to be set by divers should be large, as the stability of the work will be increased, and a decrease in the number of the joints will be effected, and a saving in the cost of laying will result, notwithstanding any small increase of expense by the necessity for the employment of more powerful raising and lowering machinery. The height of the blocks can be regulated so that the rate of laying from about low-water level exceeds the progress of the advancing tide.

Blocks for sheltered and secondary work, such as quay walls, can be made of a size a man can handle and weight he can lift, and be placed on the face, and can be grooved and dovetailed by filling in the

groove with quick-setting cement, a protection thus being afforded to concrete to be deposited *in sitû* at the back of or between face walls so erected in the case of a breakwater or pier. The unbacked-up lengths must depend upon the size and weight of the blocks and degree of pressure to which they will be subjected; however, they should not exceed from about 10 to 15 feet in length, and from 2 to 4 feet in height, the work being constructed in compartments. The surface of the concrete should be protected after deposition. It may be advisable to coat the exposed faces of blocks with a half, or one-inch coat of 1 to 1 Portland cement mortar.

If possible, the joints of all blockwork should be grouted with neat cement, see Chapter XI. Great attention should be given to the joints, and the blocks should have grooves made in them, to be filled *in sitû* with strong concrete or cement grout, thus connecting the blocks, the only objection to such grooves and joggles being, that if one block settles, others are affected.

The deposition of blocks on a foundation is a matter requiring attention when considering the question of bond. By placing one block upon another of the same size, if the under block subsides, the superimposed block is alone moved; but, if a bond is adopted, the blocks will overlap, and any subsidence of the base will affect the whole structure in a greater or lesser degree; hence placing blocks upon a rubble mound that will settle, for about one-third will be interstices, is not a method to be recommended, as the blocks should be set upon a firm natural foundation or a

monolithic concrete bed, such as the sack-blocks used at Newhaven and La Guaira breakwaters, extending the whole width of the structure, and projecting a few feet on each side.

If the foundation upon which the blocks are to rest is soft and yielding, it is better not to have a longitudinal bond, but simply to place the blocks one upon another, or laterally bond them only, if they cannot conveniently and economically be made to extend the whole transverse width of the work; and there should be no longitudinal bond, in order that if the settlement is unequal it can be readily altered without affecting any other length of the work. It should also be borne in mind that it is impossible to as firmly bed a block upon two or more blocks as it can be done upon one. In blockwork it is important to have a solid course or cap at the top, extending across the whole width of a pier or breakwater, and of a thickness not less than four feet, to bind the structure together, and if the hearting is of different or a weaker material to the side walls, it is of increased importance. Before the cap is attached, the hearting should be consolidated. On a yielding foundation, the sack-block, bag, or depositing concrete *in sitû* systems are to be preferred, unless in exceptional cases, as then a more monolithic mass is formed, and settlement does not so deleteriously affect the stability, and may not at all.

All vacuities between the blocks should be immediately filled with cement grout, which can be temporarily protected from the wash of water either by bags, timber strips, or other covering; for sea-water

should never be allowed to enter the joints, as a structure may become seriously impaired from that cause alone.

Before concrete blocks are deposited, the ground should be cleared either by divers or by dredging, and the blocks under water must be laid by divers, unless random work is adopted; and, if so, a long time should be allowed for it to take a permanent set. The usual practice was to set them dry below low-water level, and in cement mortar above that level; but now, by means of the tried and successful system of Portland cement grout, they can and should be entirely filled with it, and it may be advisable and necessary to join the blocks together by clamps, in order not only to strengthen the work, but to keep the blocks in place until the next course is deposited. Vertical grooves can be formed in the sides of each block, and when placed side by side concrete can be deposited in the hollow, thus dowelling the joints, and no unoccupied space should be left. In order to tie the blocks together, they are sometimes studded with rough projecting stones, all vacuities being filled, after deposition, with concrete. As previously named, of course, there may be situations in which the plain joint is preferable, or none other required; but it depends upon the nature of the foundation, and the degree of violence of the waves to which the blocks will be subject during and after setting. At Madras harbour breakwater, the concrete blocks are not fastened or bonded in any way to the adjoining ones, except that on the top side of each block there is a joggle, 2 feet by 1 foot $1\frac{1}{2}$ inch at one end, tapering to 2 feet at the

other end, and this fits with 3 inches play into a corresponding recess in the under side of the block above.

At Kurrachee, the inclination at which the blocks are placed is 47° 45′, determined by experiment with a model; it was just sufficient to bring the centre of gravity of each block above the face of the block against which it leans, so as to prevent any tendency of the blocks to tip forward during settlement. At Colombo breakwater the blocks are set at an angle with the horizon of 68°, or a slope of 1 in 3.

At Manora breakwater, the blocks are laid at an angle of 75° or 76°, an inclination of about three inches to one foot; an angle of 60° has also been proposed.

Where the sloping block system is used, the underfaces of the base-blocks are often made at an angle so as to lie flat at the bottom.

The more acute the angle at which the blocks are laid, the greater must be the length of the jib of the crane, or "titan." When the foundation is yielding and insecure, by having inclined courses, it seems to be generally considered that the blocks can subside without cracking or damage; but where the seas are heavy, and in an exposed situation, on similar soil, the recoil of the waves would probably scoop out the foundation if the vertical system of breakwater was adopted, unless the blocks are deposited upon a firm rubble mound at its base, consolidated by Portland cement grout and every other means that can be adopted, extending to three or four times the width of the breakwater; or on the to be preferred concrete sack-block method of

artificial foundation; then as the sea erodes the natural foundation on each side the mound will fall into it outside the vertical pier built upon the central portion of the mound, and will form its slope of stability, which will not afterwards be disturbed.

In concrete blockwork, exposed to the action of the sea, it is important that the blocks bear upon each other, and that the superincumbent weight is not removed, which may be the case if they are loosened through the sinking or unequal settlement of the foundation. It is difficult, however, to thoroughly bed by hand concrete blocks when under water, for mortar cannot be laid between them; and unless they are very carefully made to identical moulds and have perfect corners, and even, level, and equal surfaces on all sides which will be in contact, they will be irregularly supported, or only at their edges or ends.

Great care should be taken in all concrete block work, that there are no vacuities, or open joints, or fissures. If there is any unoccupied space it will be filled by the waves, and as the time between them may not be sufficient for the water to escape, when each successive wave strikes the work, a sudden violent hydraulic pressure will be created, which may push the blocks on the harbour side from their correct position. Even if the water has time to leak away, the air may become compressed by the action of the waves, which will affect the blocks on the harbour side only; therefore, the joints of breakwaters and all work exposed to the sea, within the limits of wave action, should be very carefully closed,

and if cracks, or fissures appear, or any joints become open, they should immediately be filled, to prevent any accumulation of water in them, or the air in them becoming suddenly compressed. Probably the best way to fill up cracks, or gaps in concrete walls exposed to water, is to place a covering of wood over the joint or fissure to prevent the cement from running out or being washed away, and to gently deposit therein quick-setting cement, or a stiff impervious cement grout, and the Portland cement grout method may be considered to be the only one yet devised that securely closes the joints in such situations.

A mere comparison of the weight or size of blocks is not necessarily a criterion as to their relative stability. By simply adding to the length and height of a block, the surface exposed to the sea is equally increased, but by a greater width transversely with the line of the pier the resistance to motion is augmented. The effective increase of stability through additional weight and size can, therefore, only be measured upon the horizontal line of cross section of the pier.

All unprotected corners of concrete blocks should have rounded edges, to prevent injury from wear and tear, or from blows, and to obviate a comparatively thin angular surface being presented to the action of the weather and the sea.

Blocks in the same structure are sometimes made of different proportions of cement, sand, and gravel, the strongest mixture being placed in the most exposed situations. It is advisable, by way of precaution, to

place experimental blocks, made of different proportions of materials, in an exposed position upon the site of the works, to see the effect the action of the waves has upon them ; and also if the bag system is used, bags should be similarly tried. The hardness and general cohesion of a block can be approximately tested by a hammer or steel-pointed bar. If the stones only loosely adhere to the blocks, it is a sign that there is not sufficient cement in the concrete.

It is most important to make the blocks exactly the same size, and all the surfaces that come in contact should be even, level, and identical in shape, in order to ensure equal setting and bearing, and prevent splitting and scaling, more especially with blocks set dry, i. e. generally those below low water, as the solidity of the work depends upon their being properly and equally set one upon the other, and their having similar surfaces. When set in mortar small inequalities can be removed, and the grout system of jointing decreases the importance of uniformity in the size of the blocks. At Leghorn, the large concrete blocks used in random work assumed a slope of stability of about two-thirds to one.

Quay-walls can be constructed of concrete hollow cylinders, if the soil is loose, and be sunk therein, and be filled with concrete, or with damp sand well rammed if the bottom is sealed from water. Rings of the wells can be notched and cemented together and be placed upon the cutting edge on land before deposition. The bottom ring should be richer in cement than the other rings.

Mr. D. Cunningham, at Dundee Harbour, employed hollow blocks, and found that large concrete hollow blocks can be so thinly constructed as to float by their own buoyancy. They can be towed to the site, sunk, and filled, the internal concrete being thus deposited in still water.

Since the first edition of this book was issued, the block system has advanced in favour, and as it has been shown that blocks can be reliably cemented together under water by means of cement grout, the important objection of open joints in the block system is removed.

It would appear that the block system, i. e. Portland cement concrete set in air with Portland cement grout joints, and the sack-block method of construction in plastic concrete, by which it is protected from currents and held in place until set, are perhaps, the best suited for exposed marine work.

CHAPTER XVIII.

THE BAG SYSTEM.

Adaptation—Filling the bags—Work of divers, &c.

THE system of depositing bags of plastic concrete has been used with success, and is particularly useful for levelling stable or rocky foundations, and for making a platform for preventing the scour from the recoil of the waves from a structure. Among the advantages claimed for it are that accurate levelling of the foundations is not required, as the bags fit themselves into the undulations of the ground, and lie close together, and a cheap and expeditious level foundation is, therefore, obtained, especially on rock, without the necessity of levelling the ground ; but if the foundation is fine sand, or of a soft, yielding nature, the bag system for foundations may fail, and a method must be devised for equally distributing the weight over the whole area of the ground by fascine work, the rubble mound system thoroughly consolidated and grouted, or by very large flat bags thoroughly interlocked, which must extend beyond the faces for a distance equal to, or double the width of the vertical portion of the pier. In all works it is advisable to extend the bags from 6 to 10 feet beyond the face of the structure to be built upon it, to prevent cracks, and a tendency of the bags to fall away

from the face of the wall; and there is not a good bed for the superstructure unless the bag foundation projects considerably.

Economy is also claimed for this method of construction, because the expense of making to a particular form, and the transport of heavy blocks is obviated, and the bags taking a bearing and spreading out to fit others, become more stable in their resistance to the waves than cubical or prismatic blocks simply placed one upon another. They have been used for all the constantly submerged portions of a breakwater, but it is found that from a few feet below the level of low water, care must be taken to protect the bags from being torn by the wash of the sea before the concrete has had time to harden, and the bags are sometimes of double thickness to afford greater protection; but cement concrete, if exposed to the action of the tide only in bags of sail-cloth or jute canvas, weighing about 20 ounces per yard, will set in a solid mass, and not much of the cement will be washed out.

In using bagwork in an exposed situation there is a loss of material and time, as the bags sometimes burst and become broken up and dispersed; but there is no damage from this cause if blocks are used, and men can be employed in rough weather making the blocks when setting operations cannot be performed. On the other hand, if the work is situated in a sheltered position, the system of covering concrete with sail-cloth, or placing it in bags, is not required unless currents exist, and the depositing *in sitû* method of construction can be adopted.

Heavy seas will often tear up and remove the sail-cloth bagging from the concrete, but in ordinary weather it will protect the mass until it has set, which is a great advantage.

It is advisable, owing to the interstices between the bags, to keep the application of the bag system a few feet below low water level, so that they may not be exposed to the air which may get between the joints, become compressed, and blow out the work; and similarly a severe hydraulic pressure may be created by wave action between the joints, and it is always best to fill any vacuities even below the limits of wave action.

The bags of concrete are usually deposited by means of self-acting discharging boxes lowered from an ordinary barge, being so made that a bag of the same shape as the box or skip, is fitted into and temporarily fixed at the top; when this operation is completed, it is filled with concrete, and the bag is sewn up, or a hopper barge is employed which drops her cargo of concrete in bag or bags over the prepared site, but the cast should be as little as possible. From 5 to 20 tons weight of concrete is generally put into a bag, or about 3 to 12 cubic yards; but bags of 20 to 50 tons, deposited from a hopper barge, are frequently used; and bags containing 100 tons and upwards have been employed, notably, at La Guaira Breakwater by Mr. Carey, M. Inst. C.E.

It is found in practice that the bags fit and interlock into one another, notwithstanding the sacking; although the adhesion of sack to sack does not of course nearly equal that of concrete to concrete, as the sacking pre-

vents the chemical action of crystallisation between any masses of concrete in bags, and the joints are therefore defective unless grouted, but the bags become firmly wedged. There is a limit beyond which the amount of concrete placed in a bag cannot extend with ordinary sacking, as the concrete spreads and bursts the bags.

The bags should be guided to their position by means of divers, who should give information respecting the required dimensions of a bag to level the foundations, an allowance being made for subsidence and the flattening and spreading of the bag. Irregularities are generally corrected by beating the bags down with heavy rammers immediately on deposition, which should be done as quickly as possible, so as not to interfere with the process of setting; or the top of the bag is removed, and the material cut off to the required level, and covered up with sacking. The divers should be instructed to guide and gently ram the bags so that they are packed closely together; if this is done, no difficulty will be experienced in the joints of the bags, and the space between them will not generally exceed about three inches, but, as a rule, the larger the bags the greater the interstices.

The bags pack better when they are not very tightly filled, and the concrete not made too quick-setting, but there is some trouble to keep them square and level; and it is well, especially in large bags, to carefully fill the ends, as the concrete usually, during deposition, settles towards the centre, the bag slightly doubling up.

If necessary, small angular stones can be put in by

divers in any vacuities, and neat cement grout can be poured gently through a pipe between the joints, which will help to join the bags. It is of great importance that the concrete in bagwork be thoroughly incorporated and mixed, in order that it may not strip or scale.

If concrete block work is to be placed upon concrete bags, the point of contact of the two systems should not be within the limits of wave action, and, therefore, the bags should only reach to a few feet below low water.

The five preceding chapters should be read collectively, as the subjects treated in them are intimately connected.

MEMORANDA.

	Approximate
Fresh Water, weight per cubic foot in pounds	62·4
Ordinary Sea Water (containing about 3½ per cent. of different salts), weight per cubic foot in pounds	64·05
The Dead Sea Water (containing about 24½ per cent. of different salts), weight per cubic foot in pounds	71·175

Weight of 1 bushel of fresh water	= 79·87 pounds.
" " ordinary sea water	= 81·98 "
" 1 gallon of fresh water	= 9·98, say 10 pounds.
" " ordinary sea water	= 10·25 pounds.

Freezing Point, fresh water, 32° F.

" " salt water, 1 part salt, 4 parts water, 7° F.

" " brine, 1 part salt, 3 parts water, 4° F.

---

1 gallon = ·16 of a cubic foot.
8 gallons = 1 bushel.
1 bushel = 1·28 cubic foot = 2218·19 cubic inches.
1 cubic yard = 21 net bushels.
1 cubic foot = ·781 of a bushel.

INDEX.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

INDUSTRIES.

"This book is out of the run of ordinary professional works, inasmuch as it is intended, not so much for the purpose of showing how public works are to be carried out, as to point out some of the tricks which are practised by those who do not wish to carry them out properly, and to name some methods, founded on practical experience, adopted by sub-contractors and others to cheaply and quickly execute work.

"The young engineer or inspector will find many things in the book which will at least cause him to pay attention to special points in the different departments of civil engineering construction. Such matters as piles, which are chiefly hidden from view, seem to require careful inspection, and in fact all work which is covered up when the structure is completed."

INDIAN ENGINEERING.

"This is an entertaining little book. It abounds with stories of gross cheating. Its publication is not likely to corrupt the morals of native contractors, some of whom could give points to Bill Dark (who is recounting his 'dodges'), inasmuch as that worthy claimed to own a conscience, though it is not very prominent, and always to draw the line somewhere—always put some lime in his mortar and some headers in his masonry.

"The ingenuity displayed in hiding the results of some of the frauds may be useful in setting young engineers on their guard against the over-plausible."

THE ENGINEER AND IRON TRADES ADVERTISER (Scotland).

"The somewhat uncommon title of this book will in itself prove a ready attraction to the ordinary student of current literature. The title page alone is characterised by a curious vein of humour. The author has, however, a serious and a most important object in view.

"There is a peculiar charm in it not usually found in works where technical details require to be recorded. The many 'dodges' indulged in by these ideal contractors will come as 'eye-openers' to those unacquainted with the subject. We have no hesitation in saying that the volume before us is likely to serve a good purpose, and it is deserving of a wide circulation."

NOTES ON CONCRETE AND WORKS IN CONCRETE.

By JOHN NEWMAN,

Assoc. M. Inst. C.E.

REVIEWS OF THE PRESS.

FIRST EDITION.

Engineering.

"*An epitome of the best practice which may be relied upon not to mislead.*

"The successful construction of works in concrete is a difficult matter to explain in books.

"All the points which open the way to bad work are carefully pointed out."

Iron.

"As numerous examples are cited of the use of concrete in public works, and details supplied, *the book will greatly assist engineers engaged upon such works.*"

The Builder.

"A very practical little book, carefully compiled, and *one which all writers of specifications for concrete work would do well to peruse.*

"*The book contains reliable information for all engaged upon public works.*

"A perusal of Mr. Newman's valuable little handbook will point out the importance of a more careful investigation of the subject than is usually supposed to be necessary."

AMERICAN PRESS.

Building.

"To accomplish so much in so limited a space, the subject-matter has been confined to chapters.

"*We take pleasure in saying that this is the most admirable and complete handbook on concretes for engineers of which we have knowledge.*"

E. & F. N. SPON, 125 STRAND, LONDON.

BOOKS RELATING TO APPLIED SCIENCE,

PUBLISHED BY

E. & F. N. SPON,

LONDON: 125, STRAND.

NEW YORK: 12, CORTLANDT STREET.

The Engineers' Sketch-Book of Mechanical Movements, Devices, Appliances, Contrivances, Details employed in the Design and Construction of Machinery for every purpose. Collected from numerous Sources and from Actual Work. Classified and Arranged for Reference. *Nearly* 2000 *Illustrations.* By T. B. BARBER, Engineer. Second Edition, 8vo, cloth, 7*s.* 6*d.*

A Pocket-Book for Chemists, Chemical Manufacturers, Metallurgists, Dyers, Distillers, Brewers, Sugar Refiners, Photographers, Students, etc., etc. By THOMAS BAYLEY, Assoc. R.C. Sc. Ireland, Analytical and Consulting Chemist and Assayer. Fifth edition, 481 pp., royal 32mo, roan, gilt edges, 5*s.*

SYNOPSIS OF CONTENTS:

Atomic Weights and Factors—Useful Data—Chemical Calculations—Rules for Indirect Analysis—Weights and Measures—Thermometers and Barometers—Chemical Physics—Boiling Points, etc.—Solubility of Substances—Methods of Obtaining Specific Gravity—Conversion of Hydrometers—Strength of Solutions by Specific Gravity—Analysis—Gas Analysis—Water Analysis—Qualitative Analysis and Reactions—Volumetric Analysis—Manipulation—Mineralogy—Assaying—Alcohol—Beer—Sugar—Miscellaneous Technological matter relating to Potash, Soda, Sulphuric Acid, Chlorine, Tar Products, Petroleum, Milk, Tallow, Photography, Prices, Wages, Appendix, etc., etc.

Electricity, its Theory, Sources, and Applications. By JOHN T. SPRAGUE, M. Inst. E.E. Third edition, thoroughly revised and extended, *with numerous illustrations and tables*, crown 8vo, cloth, 15*s.*

Electric Toys. Electric Toy-Making, Dynamo Building and Electric Motor Construction for Amateurs. By T. O'CONOR SLOANE, Ph.D. *With cuts*, square 16mo, cloth, 4*s.* 6*d.*

The Phonograph, and How to Construct it. With a Chapter on Sound. By W. GILLETT. *With engravings and full working drawings*, crown 8vo, cloth, 5*s.*

Just Published, in Demy 8vo, cloth, containing 975 pages and 250 Illustrations, price 7s. 6d.

SPONS' HOUSEHOLD MANUAL:

A Treasury of Domestic Receipts and Guide for Home Management.

PRINCIPAL CONTENTS.

Hints for selecting a good House, pointing out the essential requirements for a good house as to the Site, Soil, Trees, Aspect, Construction, and General Arrangement; with instructions for Reducing Echoes, Waterproofing Damp Walls, Curing Damp Cellars.

Sanitation.—What should constitute a good Sanitary Arrangement; Examples (with Illustrations) of Well- and Ill-drained Houses; How to Test Drains; Ventilating Pipes, etc.

Water Supply.—Care of Cisterns; Sources of Supply; Pipes; Pumps; Purification and Filtration of Water.

Ventilation and Warming.—Methods of Ventilating without causing cold draughts, by various means; Principles of Warming; Health Questions; Combustion; Open Grates; Open Stoves; Fuel Economisers; Varieties of Grates; Close-Fire Stoves; Hot-air Furnaces; Gas Heating; Oil Stoves; Steam Heating; Chemical Heaters; Management o Flues; and Cure of Smoky Chimneys.

Lighting.—The best methods of Lighting; Candles, Oil Lamps, Gas, Incandescent Gas, Electric Light; How to test Gas Pipes; Management of Gas.

Furniture and Decoration.—Hints on the Selection of Furniture; on the most approved methods of Modern Decoration; on the best methods of arranging Bells and Calls How to Construct an Electric Bell.

Thieves and Fire.—Precautions against Thieves and Fire; Methods of Detection Domestic Fire Escapes; Fireproofing Clothes, etc.

The Larder.—Keeping Food fresh for a limited time; Storing Food without change, such as Fruits, Vegetables, Eggs, Honey, etc.

Curing Foods for lengthened Preservation, as Smoking, Salting, Canning, Potting, Pickling, Bottling Fruits, etc.; Jams, Jellies, Marmalade, etc.

The Dairy.—The Building and Fitting of Dairies in the most approved modern style; Butter-making; Cheesemaking and Curing.

The Cellar.—Building and Fitting; Cleaning Casks and Bottles; Corks and Corking; Aërated Drinks; Syrups for Drinks; Beers; Bitters; Cordials and Liqueurs; Wines; Miscellaneous Drinks.

The Pantry.—Bread-making; Ovens and Pyrometers; Yeast; German Yeast; Biscuits; Cakes; Fancy Breads; Buns.

The Kitchen.—On Fitting Kitchens; a description of the best Cooking Ranges, close and open; the Management and Care of Hot Plates, Baking Ovens, Dampers, Flues, and Chimneys; Cooking by Gas; Cooking by Oil; the Arts of Roasting, Grilling, Boiling, Stewing, Braising, Frying.

Receipts for Dishes.—Soups, Fish, Meat, Game, Poultry, Vegetables, Salads, Puddings, Pastry, Confectionery, Ices, etc., etc.; Foreign Dishes.

The Housewife's Room.—Testing Air, Water, and Foods; Cleaning and Renovating; Destroying Vermin.

Housekeeping, Marketing.

The Dining-Room.—Dietetics; Laying and Waiting at Table; Carving; Dinners, Breakfasts, Luncheons, Teas, Suppers, etc.

The Drawing-Room.—Etiquette; Dancing; Amateur Theatricals; Tricks and Illusions; Games (indoor).

The Bedroom and Dressing-Room; Sleep; the Toilet; Dress; Buying Clothes; Outfits; Fancy Dress.

The Nursery.—The Room; Clothing; Washing; Exercise; Sleep; Feeding; Teething; Illness; Home Training.

The Sick-Room.—The Room; the Nurse; the Bed; Sick Room Accessories; Feeding Patients; Invalid Dishes and Drinks; Administering Physic; Domestic Remedies; Accidents and Emergencies; Bandaging; Burns; Carrying Injured Persons; Wounds; Drowning; Fits Frost-bites; Poisons and Antidotes; Sunstroke; Common Complaints; Disinfection, etc.

The Bath-Room.—Bathing in General; Management of Hot-Water System.

The Laundry.—Small Domestic Washing Machines, and methods of getting up linen Fitting up and Working a Steam Laundry.

The School-Room.—The Room and its Fittings; Teaching, etc.

The Playground.—Air and Exercise; Training; Outdoor Games and Sports.

The Workroom.—Darning, Patching, and Mending Garments.

The Library.—Care of Books.

The Garden.—Calendar of Operations for Lawn, Flower Garden, and Kitchen Garden.

The Farmyard.—Management of the Horse, Cow, Pig, Poultry, Bees, etc., etc.

Small Motors.—A description of the various small Engines useful for domestic purposes, from 1 man to 1 horse power, worked by various methods, such as Electric Engines, Gas Engines, Petroleum Engines, Steam Engines, Condensing Engines, Water Power, Wind Power, and the various methods of working and managing them.

Household Law.—The Law relating to Landlords and Tenants, Lodgers, Servants, Parochial Authorities, Juries, Insurance, Nuisance, etc.

On Designing Belt Gearing. By E. J. COWLING WELCH, Mem. Inst. Mech. Engineers, Author of 'Designing Valve Gearing.' Fcap. 8vo, sewed, 6*d.*

A Handbook of Formulæ, Tables, and Memoranda, for Architectural Surveyors and others engaged in Building. By J. T. HURST, C.E. Fourteenth edition, royal 32mo, roan, 5*s.*

"It is no disparagement to the many excellent publications we refer to, to say that in our opinion this little pocket-book of Hurst's is the very best of them all, without any exception. It would be useless to attempt a recapitulation of the contents, for it appears to contain almost *everything* that anyone connected with building could require, and, best of all, made up in a compact form for carrying in the pocket, measuring only 5 in. by 3 in., and about ¾ in. thick, in a limp cover. We congratulate the author on the success of his laborious and practically compiled little book, which has received unqualified and deserved praise from every professional person to whom we have shown it."—*The Dublin Builder.*

Tabulated Weights of Angle, Tee, Bulb, Round, Square, and Flat Iron and Steel, and other information for the use of Naval Architects and Shipbuilders. By C. H. JORDAN, M.I.N.A. Fourth edition, 32mo, cloth, 2*s.* 6*d.*

A Complete Set of Contract Documents for a Country Lodge, comprising Drawings, Specifications, Dimensions (for quantities), Abstracts, Bill of Quantities, Form of Tender and Contract, with Notes by J. LEANING, printed in facsimile of the original documents, on single sheets fcap., in paper case, 10*s.*

A Practical Treatise on Heat, as applied to the Useful Arts; for the Use of Engineers, Architects, &c. By THOMAS BOX. *With 14 plates.* Sixth edition, crown 8vo, cloth, 12*s.* 6*d.*

A Descriptive Treatise on Mathematical Drawing Instruments: their construction, uses, qualities, selection, preservation, and suggestions for improvements, with hints upon Drawing and Colouring. By W. F. STANLEY, M.R.I. Sixth edition, *with numerous illustrations,* crown 8vo, cloth, 5*s.*

Quantity Surveying. By J. LEANING. With 42 illustrations. Second edition, revised, crown 8vo, cloth, 9*s*.

CONTENTS:

A complete Explanation of the London Practice.
General Instructions.
Order of Taking Off.
Modes of Measurement of the various Trades.
Use and Waste.
Ventilation and Warming.
Credits, with various Examples of Treatment.
Abbreviations.
Squaring the Dimensions.
Abstracting, with Examples in illustration of each Trade.
Billing.
Examples of Preambles to each Trade.
Form for a Bill of Quantities.
Do. Bill of Credits.
Do. Bill for Alternative Estimate.
Restorations and Repairs, and Form of Bill.
Variations before Acceptance of Tender.
Errors in a Builder's Estimate.
Schedule of Prices.
Form of Schedule of Prices.
Analysis of Schedule of Prices.
Adjustment of Accounts.
Form of a Bill of Variations.
Remarks on Specifications.
Prices and Valuation of Work, with Examples and Remarks upon each Trade.
The Law as it affects Quantity Surveyors, with Law Reports.
Taking Off after the Old Method.
Northern Practice.
The General Statement of the Methods recommended by the Manchester Society of Architects for taking Quantities.
Examples of Collections.
Examples of "Taking Off" in each Trade.
Remarks on the Past and Present Methods of Estimating.

Spons' Architects' and Builders' Price Book, with useful Memoranda. Edited by W. YOUNG, Architect. Crown 8vo, cloth, red edges, 3*s*. 6*d*. *Published annually.* Nineteenth edition. *Now ready.*

Long-Span Railway Bridges, comprising Investigations of the Comparative Theoretical and Practical Advantages of the various adopted or proposed Type Systems of Construction, with numerous Formulæ and Tables giving the weight of Iron or Steel required in Bridges from 300 feet to the limiting Spans; to which are added similar Investigations and Tables relating to Short-span Railway Bridges. Second and revised edition. By B. BAKER, Assoc. Inst. C.E. *Plates*, crown 8vo, cloth, 5*s*.

Elementary Theory and Calculation of Iron Bridges and Roofs. By AUGUST RITTER, Ph.D., Professor at the Polytechnic School at Aix-la-Chapelle. Translated from the third German edition, by H. R. SANKEY, Capt. R.E. With 500 *illustrations*, 8vo, cloth, 15*s*.

The Elementary Principles of Carpentry. By THOMAS TREDGOLD. Revised from the original edition, and partly re-written, by JOHN THOMAS HURST. Contained in 517 pages of letterpress, and *illustrated with* 48 *plates and* 150 *wood engravings.* Sixth edition, reprinted from the third, crown 8vo, cloth, 12*s*. 6*d*.

Section I. On the Equality and Distribution of Forces — Section II. Resistance of Timber — Section III. Construction of Floors — Section IV. Construction of Roofs — Section V. Construction of Domes and Cupolas — Section VI. Construction of Partitions— Section VII. Scaffolds, Staging, and Gantries—Section VIII. Construction of Centres for Bridges—Section IX. Coffer-dams, Shoring, and Strutting—Section X. Wooden Bridges and Viaducts—Section XI. Joints, Straps, and other Fastenings—Section XII. Timber.

The Builder's Clerk: a Guide to the Management of a Builder's Business. By THOMAS BALES. Fcap. 8vo, cloth, 1*s*. 6*d*.

Practical Gold-Mining: a Comprehensive Treatise on the Origin and Occurrence of Gold-bearing Gravels, Rocks and Ores, and the methods by which the Gold is extracted. By C. G. WARNFORD LOCK, co-Author of 'Gold: its Occurrence and Extraction.' *With* 8 *plates and* 275 *engravings in the text*, royal 8vo, cloth, 2*l.* 2*s.*

Hot Water Supply: A Practical Treatise upon the Fitting of Circulating Apparatus in connection with Kitchen Range and other Boilers, to supply Hot Water for Domestic and General Purposes. With a Chapter upon Estimating. *Fully illustrated*, crown 8vo, cloth, 3*s.*

Hot Water Apparatus: An Elementary Guide for the Fitting and Fixing of Boilers and Apparatus for the Circulation of Hot Water for Heating and for Domestic Supply, and containing a Chapter upon Boilers and Fittings for Steam Cooking. 32 *illustrations*, fcap. 8vo, cloth, 1*s.* 6*d.*

The Use and Misuse, and the Proper and Improper Fixing of a Cooking Range. Illustrated, fcap. 8vo, sewed, 6*d.*

Iron Roofs: Examples of Design, Description. *Illustrated with* 64 *Working Drawings of Executed Roofs.* By ARTHUR T. WALMISLEY, Assoc. Mem. Inst. C.E. Second edition, revised, imp. 4to, half-morocco, 3*l.* 3*s.*

A History of Electric Telegraphy, to the Year 1837. Chiefly compiled from Original Sources, and hitherto Unpublished Documents, by J. J. FAHIE, Mem. Soc. of Tel. Engineers, and of the International Society of Electricians, Paris. Crown 8vo, cloth, 9*s.*

Spons' Information for Colonial Engineers. Edited by J. T. HURST. Demy 8vo, sewed.

No. 1, Ceylon. By ABRAHAM DEANE, C.E. 2*s.* 6*d.*

CONTENTS:

Introductory Remarks — Natural Productions — Architecture and Engineering — Topography, Trade, and Natural History—Principal Stations—Weights and Measures, etc., etc.

No. 2. Southern Africa, including the Cape Colony, Natal, and the Dutch Republics. By HENRY HALL, F.R.G.S., F.R.C.I. With Map. 3*s.* 6*d.*

CONTENTS:

General Description of South Africa—Physical Geography with reference to Engineering Operations—Notes on Labour and Material in Cape Colony—Geological Notes on Rock Formation in South Africa—Engineering Instruments for Use in South Africa—Principal Public Works in Cape Colony: Railways, Mountain Roads and Passes, Harbour Works, Bridges, Gas Works, Irrigation and Water Supply, Lighthouses, Drainage and Sanitary Engineering, Public Buildings, Mines—Table of Woods in South Africa—Animals used for Draught Purposes—Statistical Notes—Table of Distances—Rates of Carriage, etc.

No. 3. India. By F. C. DANVERS, Assoc. Inst. C.E. With Map. 4*s.* 6*d.*

CONTENTS:

Physical Geography of India—Building Materials—Roads—Railways—Bridges—Irrigation — River Works — Harbours — Lighthouse Buildings — Native Labour — The Principal Trees of India—Money—Weights and Measures—Glossary of Indian Terms, etc.

Our Factories, Workshops, and Warehouses: their Sanitary and Fire-Resisting Arrangements. By B. H. THWAITE, Assoc. Mem. Inst. C.E. *With* 183 *wood engravings*, crown 8vo, cloth, 9*s.*

A Practical Treatise on Coal Mining. By GEORGE G. ANDRÉ, F.G.S., Assoc. Inst. C.E., Member of the Society of Engineers. *With* 82 *lithographic plates.* 2 vols., royal 4to, cloth, 3*l.* 12*s.*

A Practical Treatise on Casting and Founding, including descriptions of the modern machinery employed in the art. By N. E. SPRETSON, Engineer. Fifth edition, with 82 *plates* drawn to scale, 412 pp., demy 8vo, cloth, 18*s.*

A Handbook of Electrical Testing. By H. R. KEMPE, M.S.T.E. Fourth edition, revised and enlarged, crown 8vo, cloth, 16*s.*

The Clerk of Works: a Vade-Mecum for all engaged in the Superintendence of Building Operations. By G. G. HOSKINS, F.R.I.B.A. Third edition, fcap. 8vo, cloth, 1*s.* 6*d.*

American Foundry Practice: Treating of Loam, Dry Sand, and Green Sand Moulding, and containing a Practical Treatise upon the Management of Cupolas, and the Melting of Iron. By T. D. WEST, Practical Iron Moulder and Foundry Foreman. Second edition, *with numerous illustrations*, crown 8vo, cloth, 10*s.* 6*d.*

The Maintenance of Macadamised Roads. By T. CODRINGTON, M.I.C.E, F.G.S., General Superintendent of County Roads for South Wales. Second edition, 8vo, cloth, 7*s.* 6*d.*

Hydraulic Steam and Hand Power Lifting and Pressing Machinery. By FREDERICK COLYER, M. Inst. C.E., M. Inst. M.E. *With* 73 *plates*, 8vo, cloth, 18*s.*

Pumps and Pumping Machinery. By F. COLYER, M.I.C.E., M.I.M.E. *With* 23 *folding plates*, 8vo, cloth, 12*s.* 6*d.*

Pumps and Pumping Machinery. By F. COLYER. Second Part. *With* 11 *large plates*, 8vo, cloth, 12*s.* 6*d.*

A Treatise on the Origin, Progress, Prevention, and Cure of Dry Rot in Timber; with Remarks on the Means of Preserving Wood from Destruction by Sea-Worms, Beetles, Ants, etc. By THOMAS ALLEN BRITTON, late Surveyor to the Metropolitan Board of Works, etc., etc. *With* 10 *plates*, crown 8vo, cloth, 7*s.* 6*d.*

The Artillery of the Future and the New Powders. By J. A. LONGRIDGE, Mem. Inst. C.E. 8vo, cloth, 5*s.*

Gas Works: their Arrangement, Construction, Plant, and Machinery. By F. COLYER, M. Inst. C.E. *With* 31 *folding plates*, 8vo, cloth, 12*s*. 6*d*.

The Municipal and Sanitary Engineer's Handbook. By H. PERCY BOULNOIS, Mem. Inst. C.E., Borough Engineer, Portsmouth. *With numerous illustrations.* Second edition, demy 8vo, cloth, 15*s*.

CONTENTS:

The Appointment and Duties of the Town Surveyor—Traffic—Macadamised Roadways—Steam Rolling—Road Metal and Breaking—Pitched Pavements—Asphalte—Wood Pavements—Footpaths—Kerbs and Gutters—Street Naming and Numbering—Street Lighting—Sewerage—Ventilation of Sewers—Disposal of Sewage—House Drainage—Disinfection—Gas and Water Companies, etc., Breaking up Streets—Improvement of Private Streets—Borrowing Powers—Artizans' and Labourers' Dwellings—Public Conveniences—Scavenging, including Street Cleansing—Watering and the Removing of Snow—Planting Street Trees—Deposit of Plans—Dangerous Buildings—Hoardings—Obstructions—Improving Street Lines—Cellar Openings—Public Pleasure Grounds—Cemeteries—Mortuaries—Cattle and Ordinary Markets—Public Slaughter-houses, etc.—Giving numerous Forms of Notices, Specifications, and General Information upon these and other subjects of great importance to Municipal Engineers and others engaged in Sanitary Work.

Metrical Tables. By Sir G. L. MOLESWORTH, M.I.C.E. 32mo, cloth, 1*s*. 6*d*.

CONTENTS.

General—Linear Measures—Square Measures—Cubic Measures—Measures of Capacity—Weights—Combinations—Thermometers.

Elements of Construction for Electro-Magnets. By Count TH. DU MONCEL, Mem. de l'Institut de France. Translated from the French by C. J. WHARTON. Crown 8vo, cloth, 4*s*. 6*d*.

A Treatise on the Use of Belting for the Transmission of Power. By J. H. COOPER. Second edition, *illustrated*, 8vo, cloth, 15*s*.

A Pocket-Book of Useful Formulæ and Memoranda for Civil and Mechanical Engineers. By Sir GUILFORD L. MOLESWORTH, Mem. Inst. C.E. *With numerous illustrations*, 744 pp. Twenty-second edition, 32mo, roan, 6*s*.

SYNOPSIS OF CONTENTS:

Surveying, Levelling, etc.—Strength and Weight of Materials—Earthwork, Brickwork, Masonry, Arches, etc.—Struts, Columns, Beams, and Trusses—Flooring, Roofing, and Roof Trusses—Girders, Bridges, etc.—Railways and Roads—Hydraulic Formulæ—Canals, Sewers, Waterworks, Docks—Irrigation and Breakwaters—Gas, Ventilation, and Warming—Heat, Light, Colour, and Sound—Gravity: Centres, Forces, and Powers—Millwork, Teeth of Wheels, Shafting, etc.—Workshop Recipes—Sundry Machinery—Animal Power—Steam and the Steam Engine—Water-power, Water-wheels, Turbines, etc.—Wind and Windmills—Steam Navigation, Ship Building, Tonnage, etc.—Gunnery, Projectiles, etc.—Weights, Measures, and Money—Trigonometry, Conic Sections, and Curves—Telegraphy—Mensuration—Tables of Areas and Circumference, and Arcs of Circles—Logarithms, Square and Cube Roots, Powers—Reciprocals, etc.—Useful Numbers—Differential and Integral Calculus—Algebraic Signs—Telegraphic Construction and Formulæ.

Hints on Architectural Draughtsmanship. By G. W. TUXFORD HALLATT. Fcap. 8vo, cloth, 1*s.* 6*d.*

Spons' Tables and Memoranda for Engineers; selected and arranged by J. T. HURST, C.E., Author of 'Architectural Surveyors' Handbook,' 'Hurst's Tredgold's Carpentry,' etc. Eleventh edition, 64mo, roan, gilt edges, 1*s.*; or in cloth case, 1*s.* 6*d.*

This work is printed in a pearl type, and is so small, measuring only $2\frac{1}{2}$ in. by $1\frac{3}{4}$ in. by $\frac{1}{4}$ in. thick, that it may be easily carried in the waistcoat pocket.

"It is certainly an extremely rare thing for a reviewer to be called upon to notice a volume measuring but $2\frac{1}{2}$ in. by $1\frac{3}{4}$ in., yet these dimensions faithfully represent the size of the handy little book before us. The volume—which contains 118 printed pages, besides a few blank pages for memoranda—is, in fact, a true pocket-book, adapted for being carried in the waistcoat pocket, and containing a far greater amount and variety of information than most people would imagine could be compressed into so small a space. . . . . The little volume has been compiled with considerable care and judgment, and we can cordially recommend it to our readers as a useful little pocket companion."—*Engineering.*

A Practical Treatise on Natural and Artificial Concrete, its Varieties and Constructive Adaptations. By HENRY REID, Author of the 'Science and Art of the Manufacture of Portland Cement.' New Edition, *with* 59 *woodcuts and* 5 *plates,* 8vo, cloth, 15*s.*

Notes on Concrete and Works in Concrete; especially written to assist those engaged upon Public Works. By JOHN NEWMAN, Assoc. Mem. Inst. C.E., crown 8vo, cloth, 4*s.* 6*d.*

Electricity as a Motive Power. By Count TH. DU MONCEL, Membre de l'Institut de France, and FRANK GERALDY, Ingénieur des Ponts et Chaussées. Translated and Edited, with Additions, by C. J. WHARTON, Assoc. Soc. Tel. Eng. and Elec. *With* 113 *engravings and diagrams,* crown 8vo, cloth, 7*s.* 6*d.*

Treatise on Valve-Gears, with special consideration of the Link-Motions of Locomotive Engines. By Dr. GUSTAV ZEUNER, Professor of Applied Mechanics at the Confederated Polytechnikum of Zurich. Translated from the Fourth German Edition, by Professor J. F. KLEIN, Lehigh University, Bethlehem, Pa. *Illustrated,* 8vo, cloth, 12*s.* 6*d.*

The French-Polisher's Manual. By a French-Polisher; containing Timber Staining, Washing, Matching, Improving, Painting, Imitations, Directions for Staining, Sizing, Embodying, Smoothing, Spirit Varnishing, French-Polishing, Directions for Re-polishing. Third edition, royal 32mo, sewed, 6*d.*

Hops, their Cultivation, Commerce, and Uses in various Countries. By P. L. SIMMONDS. Crown 8vo, cloth, 4*s.* 6*d.*

The Principles of Graphic Statics. By GEORGE SYDENHAM CLARKE, Major Royal Engineers. *With* 112 *illustrations.* Second edition, 4to, cloth, 12*s.* 6*d.*

Dynamo Tenders' Hand-Book. By F. B. BADT, late 1st Lieut. Royal Prussian Artillery. *With* 70 *illustrations.* Third edition, 18mo, cloth, 4*s.* 6*d.*

Practical Geometry, Perspective, and Engineering Drawing; a Course of Descriptive Geometry adapted to the Requirements of the Engineering Draughtsman, including the determination of cast shadows and Isometric Projection, each chapter being followed by numerous examples; to which are added rules for Shading, Shade-lining, etc., together with practical instructions as to the Lining, Colouring, Printing, and general treatment of Engineering Drawings, with a chapter on drawing Instruments. By GEORGE S. CLARKE, Capt. R.E. Second edition, *with* 21 *plates.* 2 vols., cloth, 10*s.* 6*d.*

The Elements of Graphic Statics. By Professor KARL VON OTT, translated from the German by G. S. CLARKE, Capt. R.E., Instructor in Mechanical Drawing, Royal Indian Engineering College. *With* 93 *illustrations*, crown 8vo, cloth, 5*s.*

A Practical Treatise on the Manufacture and Distribution of Coal Gas. By WILLIAM RICHARDS. Demy 4to, with *numerous wood engravings and* 29 *plates*, cloth, 28*s.*

SYNOPSIS OF CONTENTS:

Introduction — History of Gas Lighting — Chemistry of Gas Manufacture, by Lewis Thompson, Esq., M.R.C.S.—Coal, with Analyses, by J. Paterson, Lewis Thompson, and G. R. Hislop, Esqrs.—Retorts, Iron and Clay—Retort Setting—Hydraulic Main—Condensers — Exhausters — Washers and Scrubbers — Purifiers — Purification — History of Gas Holder — Tanks, Brick and Stone, Composite, Concrete, Cast-iron, Compound Annular Wrought-iron — Specifications — Gas Holders — Station Meter — Governor — Distribution—Mains—Gas Mathematics, or Formulæ for the Distribution of Gas, by Lewis Thompson, Esq.—Services—Consumers' Meters—Regulators—Burners—Fittings—Photometer—Carburization of Gas—Air Gas and Water Gas—Composition of Coal Gas, by Lewis Thompson, Esq.—Analyses of Gas—Influence of Atmospheric Pressure and Temperature on Gas—Residual Products—Appendix—Description of Retort Settings, Buildings, etc., etc.

The New Formula for Mean Velocity of Discharge of Rivers and Canals. By W. R. KUTTER. Translated from articles in the 'Cultur-Ingénieur,' by LOWIS D'A. JACKSON, Assoc. Inst. C.E. 8vo, cloth, 12*s.* 6*d.*

The Practical Millwright and Engineer's Ready Reckoner; or Tables for finding the diameter and power of cog-wheels, diameter, weight, and power of shafts, diameter and strength of bolts, etc. By THOMAS DIXON. Fourth edition, 12mo, cloth, 3*s.*

Tin: Describing the Chief Methods of Mining, Dressing and Smelting it abroad; with Notes upon Arsenic, Bismuth and Wolfram. By ARTHUR G. CHARLETON, Mem. American Inst. of Mining Engineers. *With plates*, 8vo, cloth, 12*s.* 6*d.*

Perspective, Explained and Illustrated. By G. S. CLARKE, Capt. R.E. *With illustrations*, 8vo, cloth, 3*s.* 6*d.*

Practical Hydraulics; a Series of Rules and Tables for the use of Engineers, etc., etc. By THOMAS BOX. Ninth edition, *numerous plates*, post 8vo, cloth, 5*s.*

The Essential Elements of Practical Mechanics; based on the Principle of Work, designed for Engineering Students. By OLIVER BYRNE, formerly Professor of Mathematics, College for Civil Engineers. Third edition, *with* 148 *wood engravings*, post 8vo, cloth, 7*s.* 6*d.*

CONTENTS:

Chap. 1. How Work is Measured by a Unit, both with and without reference to a Unit of Time—Chap. 2. The Work of Living Agents, the Influence of Friction, and introduces one of the most beautiful Laws of Motion—Chap. 3. The principles expounded in the first and second chapters are applied to the Motion of Bodies—Chap. 4. The Transmission of Work by simple Machines—Chap. 5. Useful Propositions and Rules.

Breweries and Maltings: their Arrangement, Construction, Machinery, and Plant. By G. SCAMELL, F.R.I.B.A. Second edition, revised, enlarged, and partly rewritten. By F. COLYER, M.I.C.E., M.I.M.E. *With* 20 *plates*, 8vo, cloth, 12*s.* 6*d.*

A Practical Treatise on the Construction of Horizontal and Vertical Waterwheels, specially designed for the use of operative mechanics. By WILLIAM CULLEN, Millwright and Engineer. *With* 11 *plates.* Second edition, revised and enlarged, small 4to, cloth, 12*s.* 6*d.*

A Practical Treatise on Mill-gearing, Wheels, Shafts, Riggers, etc.; for the use of Engineers. By THOMAS BOX. Third edition, *with* 11 *plates.* Crown 8vo, cloth, 7*s.* 6*d.*

Mining Machinery: a Descriptive Treatise on the Machinery, Tools, and other Appliances used in Mining. By G. G. ANDRÉ, F.G.S., Assoc. Inst. C.E., Mem. of the Society of Engineers. Royal 4to, uniform with the Author's Treatise on Coal Mining, containing 182 *plates*, accurately drawn to scale, with descriptive text, in 2 vols., cloth, 3*l.* 12*s.*

CONTENTS:

Machinery for Prospecting, Excavating, Hauling, and Hoisting—Ventilation—Pumping—Treatment of Mineral Products, including Gold and Silver, Copper, Tin, and Lead, Iron, Coal, Sulphur, China Clay, Brick Earth, etc.

Tables for Setting out Curves for Railways, Canals, Roads, etc., varying from a radius of five chains to three miles. By A. KENNEDY and R. W. HACKWOOD. *Illustrated* 32mo, cloth, 2*s.* 6*d.*

Practical Electrical Notes and Definitions for the use of Engineering Students and Practical Men. By W. PERREN MAYCOCK, Assoc. M. Inst. E.E., Instructor in Electrical Engineering at the Pitlake Institute, Croydon, together with the Rules and Regulations to be observed in Electrical Installation Work. Second edition. Royal 32mo, roan, gilt edges, 4*s.* 6*d.*, or cloth, red edges, 3*s.*

The Draughtsman's Handbook of Plan and Map Drawing; including instructions for the preparation of Engineering, Architectural, and Mechanical Drawings. *With numerous illustrations in the text, and* 33 *plates* (15 *printed in colours*). By G. G. ANDRÉ, F.G.S., Assoc. Inst. C.E. 4to, cloth, 9*s.*

CONTENTS:

The Drawing Office and its Furnishings—Geometrical Problems—Lines, Dots, and their Combinations—Colours, Shading, Lettering, Bordering, and North Points—Scales—Plotting—Civil Engineers' and Surveyors' Plans—Map Drawing—Mechanical and Architectural Drawing—Copying and Reducing Trigonometrical Formulæ, etc., etc.

The Boiler-maker's and Iron Ship-builder's Companion, comprising a series of original and carefully calculated tables, of the utmost utility to persons interested in the iron trades. By JAMES FODEN, author of 'Mechanical Tables,' etc. Second edition revised, *with illustrations*, crown 8vo, cloth, 5*s.*

Rock Blasting: a Practical Treatise on the means employed in Blasting Rocks for Industrial Purposes. By G. G. ANDRÉ, F.G.S., Assoc. Inst. C.E. *With* 56 *illustrations and* 12 *plates*, 8vo, cloth, 10*s.* 6*d.*

Experimental Science: Elementary, Practical, and Experimental Physics. By GEO. M. HOPKINS. *Illustrated by* 672 *engravings.* In one large vol., 8vo, cloth, 15*s.*

A Treatise on Ropemaking as practised in public and private Rope-yards, with a Description of the Manufacture, Rules, Tables of Weights, etc., adapted to the Trade, Shipping, Mining, Railways, Builders, etc. By R. CHAPMAN, formerly foreman to Messrs. Huddart and Co., Limehouse, and late Master Ropemaker to H.M. Dockyard, Deptford. Second edition, 12mo, cloth, 3*s.*

Laxton's Builders' and Contractors' Tables; for the use of Engineers, Architects, Surveyors, Builders, Land Agents, and others. Bricklayer, containing 22 tables, with nearly 30,000 calculations. 4to, cloth, 5*s.*

Laxton's Builders' and Contractors' Tables. Excavator, Earth, Land, Water, and Gas, containing 53 tables, with nearly 24,000 calculations. 4to, cloth, 5*s.*

Egyptian Irrigation. By W. WILLCOCKS, M.I.C.E., Indian Public Works Department, Inspector of Irrigation, Egypt. With Introduction by Lieut.-Col. J. C. ROSS, R.E., Inspector-General of Irrigation. *With numerous lithographs and wood engravings*, royal 8vo, cloth, 1*l.* 16*s.*

Screw Cutting Tables for Engineers and Machinists, giving the values of the different trains of Wheels required to produce Screws of any pitch, calculated by Lord Lindsay, M.P., F.R.S., F.R.A.S., etc. Cloth, oblong, 2*s.*

Screw Cutting Tables, for the use of Mechanical Engineers, showing the proper arrangement of Wheels for cutting the Threads of Screws of any required pitch, with a Table for making the Universal Gas-pipe Threads and Taps. By W. A. MARTIN, Engineer. Second edition, oblong, cloth, 1*s.*, or sewed, 6*d.*

A Treatise on a Practical Method of Designing Slide-Valve Gears by Simple Geometrical Construction, based upon the principles enunciated in Euclid's Elements, and comprising the various forms of Plain Slide-Valve and Expansion Gearing; together with Stephenson's, Gooch's, and Allan's Link-Motions, as applied either to reversing or to variable expansion combinations. By EDWARD J. COWLING WELCH, Memb. Inst. Mechanical Engineers. Crown 8vo, cloth, 6*s.*

Cleaning and Scouring: a Manual for Dyers, Laundresses, and for Domestic Use. By S. CHRISTOPHER. 18mo, sewed, 6*d.*

A Glossary of Terms used in Coal Mining. By WILLIAM STUKELEY GRESLEY, Assoc. Mem. Inst. C.E., F.G.S., Member of the North of England Institute of Mining Engineers. *Illustrated with numerous woodcuts and diagrams*, crown 8vo, cloth, 5*s.*

A Pocket-Book for Boiler Makers and Steam Users, comprising a variety of useful information for Employer and Workman, Government Inspectors, Board of Trade Surveyors, Engineers in charge of Works and Slips, Foremen of Manufactories, and the general Steam-using Public. By MAURICE JOHN SEXTON. Second edition, royal 32mo, roan, gilt edges, 5*s.*

Electrolysis: a Practical Treatise on Nickeling, Coppering, Gilding, Silvering, the Refining of Metals, and the treatment of Ores by means of Electricity. By HIPPOLYTE FONTAINE, translated from the French by J. A. BERLY, C.E., Assoc. S.T.E. *With engravings.* 8vo, cloth, 9*s.*

Barlow's Tables of Squares, Cubes, Square Roots, Cube Roots, Reciprocals of all Integer Numbers up to 10,000. Post 8vo, cloth, 6*s.*

A Practical Treatise on the Steam Engine, containing Plans and Arrangements of Details for Fixed Steam Engines, with Essays on the Principles involved in Design and Construction. By ARTHUR RIGG, Engineer, Member of the Society of Engineers and of the Royal Institution of Great Britain. Demy 4to, *copiously illustrated with woodcuts and* 96 *plates*, in one Volume, half-bound morocco, 2*l.* 2*s.*; or cheaper edition, cloth, 25*s.*

This work is not, in any sense, an elementary treatise, or history of the steam engine, but is intended to describe examples of Fixed Steam Engines without entering into the wide domain of locomotive or marine practice. To this end illustrations will be given of the most recent arrangements of Horizontal, Vertical, Beam, Pumping, Winding, Portable, Semi-portable, Corliss, Allen, Compound, and other similar Engines, by the most eminent Firms in Great Britain and America. The laws relating to the action and precautions to be observed in the construction of the various details, such as Cylinders, Pistons, Piston-rods, Connecting-rods, Cross-heads, Motion-blocks, Eccentrics, Simple, Expansion, Balanced, and Equilibrium Slide-valves, and Valve-gearing will be minutely dealt with. In this connection will be found articles upon the Velocity of Reciprocating Parts and the Mode of Applying the Indicator, Heat and Expansion of Steam Governors, and the like. It is the writer's desire to draw illustrations from every possible source, and give only those rules that present practice deems correct.

A Practical Treatise on the Science of Land and Engineering Surveying, Levelling, Estimating Quantities, etc., with a general description of the several Instruments required for Surveying, Levelling, Plotting, etc. By H. S. MERRETT. Fourth edition, revised by G. W. USILL, Assoc. Mem. Inst. C.E. 41 *plates, with illustrations and tables*, royal 8vo, cloth, 12*s.* 6*d.*

PRINCIPAL CONTENTS:

Part 1. Introduction and the Principles of Geometry. Part 2. Land Surveying; comprising General Observations—The Chain—Offsets Surveying by the Chain only—Surveying Hilly Ground—To Survey an Estate or Parish by the Chain only—Surveying with the Theodolite—Mining and Town Surveying—Railroad Surveying—Mapping—Division and Laying out of Land—Observations on Enclosures—Plane Trigonometry. Part 3. Levelling—Simple and Compound Levelling—The Level Book—Parliamentary Plan and Section—Levelling with a Theodolite—Gradients—Wooden Curves—To Lay out a Railway Curve—Setting out Widths. Part 4. Calculating Quantities generally for Estimates—Cuttings and Embankments—Tunnels—Brickwork—Ironwork—Timber Measuring. Part 5. Description and Use of Instruments in Surveying and Plotting—The Improved Dumpy Level—Troughton's Level—The Prismatic Compass—Proportional Compass—Box Sextant—Vernier—Pantagraph—Merrett's Improved Quadrant—Improved Computation Scale—The Diagonal Scale—Straight Edge and Sector. Part 6. Logarithms of Numbers—Logarithmic Sines and Co-Sines, Tangents and Co-Tangents—Natural Sines and Co-Sines—Tables for Earthwork, for Setting out Curves, and for various Calculations, etc., etc., etc.

Mechanical Graphics. A Second Course of Mechanical Drawing. With Preface by Prof. PERRY, B.Sc., F.R.S. Arranged for use in Technical and Science and Art Institutes, Schools and Colleges, by GEORGE HALLIDAY, Whitworth Scholar. 8vo, cloth, 6*s.*

The Assayer's Manual: an Abridged Treatise on the Docimastic Examination of Ores and Furnace and other Artificial Products. By BRUNO KERL. Translated by W. T. BRANNT. *With* 65 *illustrations*, 8vo, cloth, 12*s.* 6*d.*

Dynamo-Electric Machinery: a Text-Book for Students of Electro-Technology. By SILVANUS P. THOMPSON, B.A., D.Sc., M.S.T.E. [*New edition in the press.*

The Practice of Hand Turning in Wood, Ivory, Shell, etc., with Instructions for Turning such Work in Metal as may be required in the Practice of Turning in Wood, Ivory, etc.; also an Appendix on Ornamental Turning. (A book for beginners.) By FRANCIS CAMPIN. Third edition, *with wood engravings*, crown 8vo, cloth, 6*s.*

CONTENTS:

On Lathes—Turning Tools—Turning Wood—Drilling—Screw Cutting—Miscellaneous Apparatus and Processes—Turning Particular Forms—Staining—Polishing—Spinning Metals—Materials—Ornamental Turning, etc.

Treatise on Watchwork, Past and Present. By the Rev. H. L. NELTHROPP, M.A., F.S.A. *With* 32 *illustrations*, crown 8vo, cloth, 6*s.* 6*d.*

CONTENTS:

Definitions of Words and Terms used in Watchwork—Tools—Time—Historical Summary—On Calculations of the Numbers for Wheels and Pinions; their Proportional Sizes, Trains, etc.—Of Dial Wheels, or Motion Work—Length of Time of Going without Winding up—The Verge—The Horizontal—The Duplex—The Lever—The Chronometer—Repeating Watches—Keyless Watches—The Pendulum, or Spiral Spring—Compensation—Jewelling of Pivot Holes—Clerkenwell—Fallacies of the Trade—Incapacity of Workmen—How to Choose and Use a Watch, etc.

Algebra Self-Taught. By W. P. HIGGS, M.A., D.Sc., LL.D., Assoc. Inst. C.E., Author of 'A Handbook of the Differential Calculus,' etc. Second edition, crown 8vo, cloth, 2*s.* 6*d.*

CONTENTS:

Symbols and the Signs of Operation—The Equation and the Unknown Quantity—Positive and Negative Quantities—Multiplication—Involution—Exponents—Negative Exponents—Roots, and the Use of Exponents as Logarithms—Logarithms—Tables of Logarithms and Proportionate Parts—Transformation of System of Logarithms—Common Uses of Common Logarithms—Compound Multiplication and the Binomial Theorem—Division, Fractions, and Ratio—Continued Proportion—The Series and the Summation of the Series—Limit of Series—Square and Cube Roots—Equations—List of Formulæ, etc.

Spons' Dictionary of Engineering, Civil, Mechanical, Military, and Naval; with technical terms in French, German, Italian, and Spanish, 3100 pp., and *nearly* 8000 *engravings*, in super-royal 8vo, in 8 divisions, 5*l.* 8*s.* Complete in 3 vols., cloth, 5*l.* 5*s.* Bound in a superior manner, half-morocco, top edge gilt, 3 vols., 6*l.* 12*s.*

Notes in Mechanical Engineering. Compiled principally for the use of the Students attending the Classes on this subject at the City of London College. By HENRY ADAMS, Mem. Inst. M.E., Mem. Inst. C.E., Mem. Soc. of Engineers. Crown 8vo, cloth, 2*s.* 6*d.*

Canoe and Boat Building: a complete Manual for Amateurs, containing plain and comprehensive directions for the construction of Canoes, Rowing and Sailing Boats, and Hunting Craft. By W. P. STEPHENS. *With numerous illustrations and 24 plates of Working Drawings.* Crown 8vo, cloth, 9*s.*

Proceedings of the National Conference of Electricians, Philadelphia, October 8th to 13th, 1884. 18mo, cloth, 3*s.*

Dynamo-Electricity, its Generation, Application, Transmission, Storage, and Measurement. By G. B. PRESCOTT. *With 545 illustrations.* 8vo, cloth, 1*l.* 1*s.*

Domestic Electricity for Amateurs. Translated from the French of E. HOSPITALIER, Editor of "L'Electricien," by C. J. WHARTON, Assoc. Soc. Tel. Eng. *Numerous illustrations.* Demy 8vo, cloth, 6*s.*

CONTENTS:

1. Production of the Electric Current—2. Electric Bells—3. Automatic Alarms—4. Domestic Telephones—5. Electric Clocks—6. Electric Lighters—7. Domestic Electric Lighting—8. Domestic Application of the Electric Light—9. Electric Motors—10. Electrical Locomotion—11. Electrotyping, Plating, and Gilding—12. Electric Recreations—13. Various applications—Workshop of the Electrician.

Wrinkles in Electric Lighting. By VINCENT STEPHEN. *With illustrations.* 18mo, cloth, 2*s.* 6*d.*

CONTENTS:

1. The Electric Current and its production by Chemical means—2. Production of Electric Currents by Mechanical means—3. Dynamo-Electric Machines—4. Electric Lamps—5. Lead—6. Ship Lighting.

Foundations and Foundation Walls for all classes of Buildings, Pile Driving, Building Stones and Bricks, Pier and Wall construction, Mortars, Limes, Cements, Concretes, Stuccos, &c. 64 *illustrations.* By G. T. POWELL and F. BAUMAN. 8vo, cloth, 10*s.* 6*d.*

Manual for Gas Engineering Students. By D. LEE. 18mo, cloth, 1*s.*

Telephones, their Construction and Management. By F. C. ALLSOP. Crown 8vo, cloth, 5*s.*

Hydraulic Machinery, Past and Present. A Lecture delivered to the London and Suburban Railway Officials' Association. By H. ADAMS, Mem. Inst. C.E. *Folding plate.* 8vo, sewed, 1*s.*

Twenty Years with the Indicator. By THOMAS PRAY, Jun., C.E., M.E., Member of the American Society of Civil Engineers. 2 vols., royal 8vo, cloth, 12*s.* 6*d.*

Annual Statistical Report of the Secretary to the Members of the Iron and Steel Association on the Home and Foreign Iron and Steel Industries in 1889. Issued June 1890. 8vo, sewed, 5*s.*

Bad Drains, and How to Test them; with Notes on the Ventilation of Sewers, Drains, and Sanitary Fittings, and the Origin and Transmission of Zymotic Disease. By R. HARRIS REEVES. Crown 8vo, cloth, 3*s.* 6*d.*

Well Sinking. The modern practice of Sinking and Boring Wells, with geological considerations and examples of Wells. By ERNEST SPON, Assoc. Mem. Inst. C.E., Mem. Soc. Eng., and of the Franklin Inst., etc. Second edition, revised and enlarged. Crown 8vo, cloth, 10*s.* 6*d.*

The Voltaic Accumulator: an Elementary Treatise. By ÉMILE REYNIER. Translated by J. A. BERLY, Assoc. Inst. E.E. *With* 62 *illustrations*, 8vo, cloth, 9*s.*

Ten Years' Experience in Works of Intermittent Downward Filtration. By J. BAILEY DENTON, Mem. Inst. C.E. Second edition, with additions. Royal 8vo, cloth, 5*s.*

Land Surveying on the Meridian and Perpendicular System. By WILLIAM PENMAN, C.E. 8vo, cloth, 8*s.* 6*d.*

The Electromagnet and Electromagnetic Mechanism. By SILVANUS P. THOMPSON, D.Sc., F.R.S. Second edition, 8vo, cloth, 15*s.*

Incandescent Wiring Hand-Book. By F. B. BADT, late 1st Lieut. Royal Prussian Artillery. *With* 41 *illustrations and* 5 *tables.* 18mo, cloth, 4*s.* 6*d.*

A Pocket-book for Pharmacists, Medical Practitioners, Students, etc., etc. (*British, Colonial, and American*). By THOMAS BAYLEY, Assoc. R. Coll. of Science, Consulting Chemist, Analyst, and Assayer, Author of a 'Pocket-book for Chemists,' 'The Assay and Analysis of Iron and Steel, Iron Ores, and Fuel,' etc., etc. Royal 32mo, boards, gilt edges, 6*s.*

The Fireman's Guide; a Handbook on the Care of Boilers. By TEKNOLOG, föreningen T. I. Stockholm. Translated from the third edition, and revised by KARL P. DAHLSTROM, M.E. Second edition. Fcap. 8vo, cloth, 2*s.*

The Mechanician: A Treatise on the Construction and Manipulation of Tools, for the use and instruction of Young Engineers and Scientific Amateurs, comprising the Arts of Blacksmithing and Forging; the Construction and Manufacture of Hand Tools, and the various Methods of Using and Grinding them; description of Hand and Machine Processes; Turning and Screw Cutting. By CAMERON KNIGHT, Engineer. *Containing* 1147 *illustrations*, and 397 pages of letter-press. Fourth edition, 4to, cloth, 18*s.*

A Treatise on Modern Steam Engines and Boilers, including Land Locomotive, and Marine Engines and Boilers, for the use of Students. By FREDERICK COLYER, M. Inst. C.E., Mem. Inst. M.E. *With* 36 *plates.* 4to, cloth, 12*s.* 6*d.*

CONTENTS:

1. Introduction—2. Original Engines—3. Boilers—4. High-Pressure Beam Engines—5. Cornish Beam Engines—6. Horizontal Engines—7. Oscillating Engines—8. Vertical High-Pressure Engines—9. Special Engines—10. Portable Engines—11. Locomotive Engines—12. Marine Engines.

Steam Engine Management; a Treatise on the Working and Management of Steam Boilers. By F. COLYER, M. Inst. C.E., Mem. Inst. M.E. New edition, 18mo, cloth, 3*s.* 6*d.*

Aid Book to Engineering Enterprise. By EWING MATHESON, M. Inst. C.E. The Inception of Public Works, Parliamentary Procedure for Railways, Concessions for Foreign Works, and means of Providing Money, the Points which determine Success or Failure, Contract and Purchase, Commerce in Coal, Iron, and Steel, &c. Second edition, revised and enlarged, 8vo, cloth, 21*s.*

Pumps, Historically, Theoretically, and Practically Considered. By P. R. BJÖRLING. *With* 156 *illustrations.* Crown 8vo, cloth, 7*s.* 6*d.*

The Marine Transport of Petroleum. A Book for the use of Shipowners, Shipbuilders, Underwriters, Merchants, Captains and Officers of Petroleum-carrying Vessels. By G. H. LITTLE, Editor of the 'Liverpool Journal of Commerce.' Crown 8vo, cloth, 10*s.* 6*d.*

Liquid Fuel for Mechanical and Industrial Purposes. Compiled by E. A. BRAYLEY HODGETTS. *With wood engravings.* 8vo, cloth, 7*s.* 6*d.*

Tropical Agriculture: A Treatise on the Culture, Preparation, Commerce and Consumption of the principal Products of the Vegetable Kingdom. By P. L. SIMMONDS, F.L.S., F.R.C.I. New edition, revised and enlarged, 8vo, cloth, 21*s.*

Health and Comfort in House Building; or, Ventilation with Warm Air by Self-acting Suction Power. With Review of the Mode of Calculating the Draught in Hot-air Flues, and with some Actual Experiments by J. DRYSDALE, M.D., and J. W. HAYWARD, M.D. *With plates and woodcuts.* Third edition, with some New Sections, and the whole carefully Revised, 8vo, cloth, 7*s.* 6*d.*

Losses in Gold Amalgamation. With Notes on the Concentration of Gold and Silver Ores. *With six plates.* By W. MCDERMOTT and P. W. DUFFIELD. 8vo, cloth, 5*s.*

A Guide for the Electric Testing of Telegraph Cables. By Col. V. HOSKIŒR, Royal Danish Engineers. Third edition, crown 8vo, cloth, 4*s.* 6*d.*

The Hydraulic Gold Miners' Manual. By T. S. G. KIRKPATRICK, M.A. Oxon. *With* 6 *plates.* Crown 8vo, cloth, 6*s.*

"We venture to think that this work will become a text-book on the important subject of which it treats. Until comparatively recently hydraulic mines were neglected. This was scarcely to be surprised at, seeing that their working in California was brought to an abrupt termination by the action of the farmers on the *débris* question, whilst their working in other parts of the world had not been attended with the anticipated success."—*The Mining World and Engineering Record.*

A Text-Book of Tanning, embracing the Preparation of all kinds of Leather. By HARRY R. PROCTOR, F.C.S., of Low Lights Tanneries. *With illustrations.* Crown 8vo, cloth, 10*s.* 6*d.*

The Arithmetic of Electricity. By T. O'CONOR SLOANE. Crown 8vo, cloth, 4*s.* 6*d.*

The Turkish Bath: Its Design and Construction for Public and Commercial Purposes. By R. O. ALLSOP, Architect. *With plans and sections.* 8vo, cloth, 6*s.*

Earthwork Slips and Subsidences upon Public Works: Their Causes, Prevention and Reparation. Especially written to assist those engaged in the Construction or Maintenance of Railways, Docks, Canals, Waterworks, River Banks, Reclamation Embankments, Drainage Works, &c., &c. By JOHN NEWMAN, Assoc. Mem. Inst. C.E., Author of 'Notes on Concrete,' &c. Crown 8vo, cloth, 7*s.* 6*d.*

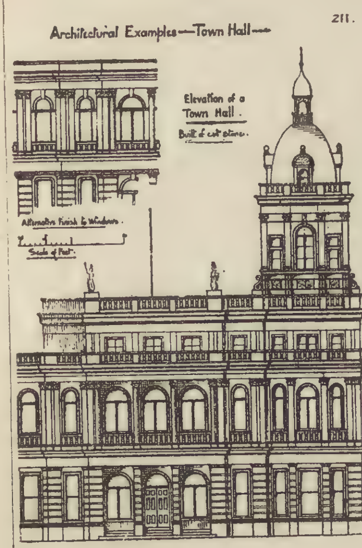
Gas and Petroleum Engines: A Practical Treatise on the Internal Combustion Engine. By WM. ROBINSON, M.E., Senior Demonstrator and Lecturer on Applied Mechanics, Physics, &c., City and Guilds of London College, Finsbury, Assoc. Mem. Inst. C.E., &c. *Numerous illustrations.* 8vo, cloth, 14*s.*

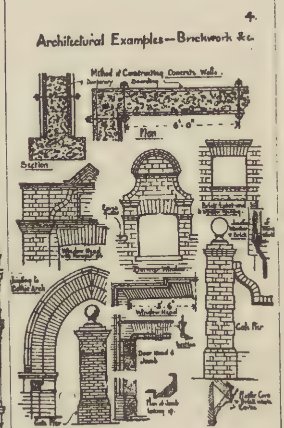
Waterways and Water Transport in Different Countries. With a description of the Panama, Suez, Manchester, Nicaraguan, and other Canals. By J. STEPHEN JEANS, Author of 'England's Supremacy,' 'Railway Problems,' &c. *Numerous illustrations.* 8vo, cloth, 14*s.*

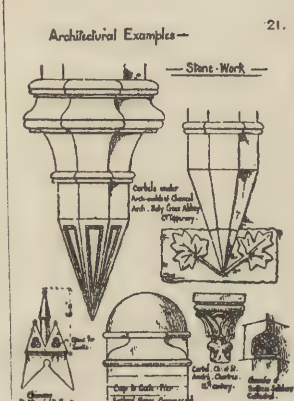
A Treatise on the Richards Steam-Engine Indicator and the Development and Application of Force in the Steam-Engine. By CHARLES T. PORTER. Fourth Edition, revised and enlarged, 8vo, cloth, 9*s.*

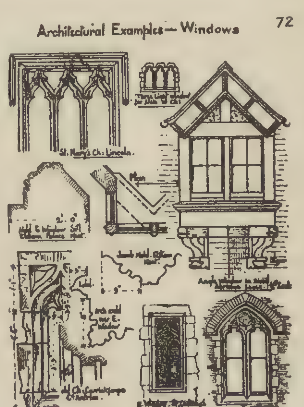
CONTENTS.

Specimen Pages, reduced from the originals.









Crown 8vo, cloth, with illustrations, 5*s.*

WORKSHOP RECEIPTS,

FIRST SERIES.

BY ERNEST SPON.

SYNOPSIS OF CONTENTS.

Bookbinding.
Bronzes and Bronzing.
Candles.
Cement.
Cleaning.
Colourwashing.
Concretes.
Dipping Acids.
Drawing Office Details.
Drying Oils.
Dynamite.
Electro - Metallurgy — (Cleaning, Dipping, Scratch-brushing, Batteries, Baths, and Deposits of every description).
Enamels.
Engraving on Wood, Copper, Gold, Silver, Steel, and Stone.
Etching and Aqua Tint.
Firework Making — (Rockets, Stars, Rains, Gerbes, Jets, Tourbillons, Candles, Fires, Lances, Lights, Wheels, Fire-balloons, and minor Fireworks).
Fluxes.
Foundry Mixtures.
Freezing.
Fulminates.
Furniture Creams, Oils, Polishes, Lacquers, and Pastes.
Gilding.
Glass Cutting, Cleaning, Frosting, Drilling, Darkening, Bending, Staining, and Painting.
Glass Making.
Glues.
Gold.
Graining.
Gums.
Gun Cotton.
Gunpowder.
Horn Working.
Indiarubber.
Japans, Japanning, and kindred processes.
Lacquers.
Lathing.
Lubricants.
Marble Working.
Matches.
Mortars.
Nitro-Glycerine.
Oils.
Paper.
Paper Hanging.
Painting in Oils, in Water Colours, as well as Fresco, House, Transparency, Sign, and Carriage Painting.
Photography.
Plastering.
Polishes.
Pottery—(Clays, Bodies, Glazes, Colours, Oils, Stains, Fluxes, Enamels, and Lustres).
Scouring.
Silvering.
Soap.
Solders.
Tanning.
Taxidermy.
Tempering Metals.
Treating Horn, Mother-o'-Pearl, and like substances.
Varnishes, Manufacture and Use of.
Veneering.
Washing.
Waterproofing.
Welding.

Besides Receipts relating to the lesser Technological matters and processes, such as the manufacture and use of Stencil Plates, Blacking, Crayons, Paste, Putty, Wax, Size, Alloys, Catgut, Tunbridge Ware, Picture Frame and Architectural Mouldings, Compos, Cameos, and others too numerous to mention.

Crown 8vo, cloth, 480 pages, with 183 illustrations, 5*s.*

WORKSHOP RECEIPTS,

THIRD SERIES.

BY C. G. WARNFORD LOCK.

Uniform with the First and Second Series.

SYNOPSIS OF CONTENTS.

Alloys.
Aluminium.
Antimony.
Barium.
Beryllium.
Bismuth.
Cadmium.
Cæsium.
Calcium.
Cerium.
Chromium.
Cobalt.
Copper.
Didymium.
Electrics.
Enamels and Glazes.
Erbium.
Gallium.
Glass.
Gold.
Indium.
Iridium.
Iron and Steel.
Lacquers and Lacquering.
Lanthanum.
Lead.
Lithium.
Lubricants.
Magnesium.
Manganese.
Mercury.
Mica.
Molybdenum.
Nickel.
Niobium.
Osmium.
Palladium.
Platinum.
Potassium.
Rhodium.
Rubidium.
Ruthenium.
Selenium.
Silver.
Slag.
Sodium.
Strontium.
Tantalum.
Terbium.
Thallium.
Thorium.
Tin.
Titanium.
Tungsten.
Uranium.
Vanadium.
Yttrium.
Zinc.
Zirconium.

WORKSHOP RECEIPTS,

FOURTH SERIES,

DEVOTED MAINLY TO HANDICRAFTS & MECHANICAL SUBJECTS.

BY C. G. WARNFORD LOCK.

250 Illustrations, with Complete Index, and a General Index to the Four Series, 5s.

Waterproofing — rubber goods, cuprammonium processes, miscellaneous preparations.

Packing and Storing articles of delicate odour or colour, of a deliquescent character, liable to ignition, apt to suffer from insects or damp, or easily broken.

Embalming and Preserving anatomical specimens.

Leather Polishes.

Cooling Air and Water, producing low temperatures, making ice, cooling syrups and solutions, and separating salts from liquors by refrigeration.

Pumps and Siphons, embracing every useful contrivance for raising and supplying water on a moderate scale, and moving corrosive, tenacious, and other liquids.

Desiccating—air- and water-ovens, and other appliances for drying natural and artificial products.

Distilling—water, tinctures, extracts, pharmaceutical preparations, essences, perfumes, and alcoholic liquids.

Emulsifying as required by pharmacists and photographers.

Evaporating—saline and other solutions, and liquids demanding special precautions.

Filtering—water, and solutions of various kinds.

Percolating and Macerating.

Electrotyping.

Stereotyping by both plaster and paper processes.

Bookbinding in all its details.

Straw Plaiting and the fabrication of baskets, matting, etc.

Musical Instruments—the preservation, tuning, and repair of pianos, harmoniums, musical boxes, etc.

Clock and Watch Mending—adapted for intelligent amateurs.

Photography—recent development in rapid processes, handy apparatus, numerous recipes for sensitizing and developing solutions, and applications to modern illustrative purposes.

Crown 8vo, cloth, with 373 illustrations, price 5*s.*

WORKSHOP RECEIPTS,

FIFTH SERIES.

BY C. G. WARNFORD LOCK, F.L.S.

Containing many new Articles, as well as additions to Articles included in the previous Series, as follows, viz. :—

Anemometers.
Barometers, How to make.
Boat Building.
Camera Lucida, How to use.
Cements and Lutes.
Cooling.
Copying.
Corrosion and Protection of Metal Surfaces.
Dendrometer, How to use.
Desiccating.
Diamond Cutting and Polishing. Electrics. New Chemical Batteries, Bells, Commutators, Galvanometers, Cost of Electric Lighting, Microphones, Simple Motors, Phonogram and Graphophone, Registering Apparatus, Regulators, Electric Welding and Apparatus, Transformers.
Evaporating.
Explosives.
Filtering.
Fireproofing, Buildings, Textile Fabrics.
Fire-extinguishing Compounds and Apparatus.
Glass Manipulating. Drilling, Cutting, Breaking, Etching, Frosting, Powdering, &c.
Glass Manipulations for Laboratory Apparatus.
Labels. Lacquers.
Illuminating Agents.
Inks. Writing, Copying, Invisible, Marking, Stamping.
Magic Lanterns, their management and preparation of slides.
Metal Work. Casting Ornamental Metal Work, Copper Welding, Enamels for Iron and other Metals, Gold Beating, Smiths' Work.
Modelling and Plaster Casting.
Netting.
Packing and Storing. Acids, &c.
Percolation.
Preserving Books.
Preserving Food, Plants, &c.
Pumps and Syphons for various liquids.
Repairing Books.
Rope Tackle.
Stereotyping.
Taps, Various.
Tobacco Pipe Manufacture.
Tying and Splicing Ropes.
Velocipedes, Repairing.
Walking Sticks.
Waterproofing.

MECHANICAL MANIPULATION.

THE MECHANICIAN:

A TREATISE ON THE CONSTRUCTION AND MANIPULATION OF TOOLS, FOR THE USE AND INSTRUCTION OF YOUNG ENGINEERS AND SCIENTIFIC AMATEURS;

Comprising the Arts of Blacksmithing and Forging ; the Construction and Manufacture of Hand Tools, and the various Methods of Using and Grinding them ; the Construction of Machine Tools, and how to work them ; Turning and Screw-cutting ; the various details of setting out work, &c., &c.

By CAMERON KNIGHT, Engineer.

96 4to plates, containing 1147 illustrations, and 397 pages of letterpress, second edition, reprinted from the first, **4to, cloth, 18s.**

Of the six chapters constituting the work, the first is devoted to forging ; in which the fundamental principles to be observed in making forged articles of every class are stated, giving the proper relative positions for the constituent fibres of each article, the mode of selecting proper quantities of material, steam-hammer operations, shaping-moulds, and the manipulations resorted to for shaping the component masses to the intended forms.

Engineers' tools and their construction are next treated, because they must be used during all operations described in the remaining chapters, the author thinking that the student should first acquire knowledge of the apparatus which he is supposed to be using in the course of the processes given in Chapters 4, 5, and 6. In the fourth chapter planing and lining are treated, because these are the elements of machine-making in general. The processes described in this chapter are those on which all accuracy of fitting and finishing depend. The next chapter, which treats of shaping and slotting, the author endeavours to render comprehensive by giving the hand-shaping processes in addition to the machine-shaping.

In many cases hand-shaping is indispensable, such as sudden breakage, operations abroad, and on board ship, also for constructors having a limited number of machines. Turning and screw-cutting occupy the last chapter. In this, the operations for lining, centering, turning, and screw-forming are detailed and their principles elucidated.

The Mechanician is the result of the author's experience in engine making during twenty years ; and he has concluded that, however retentive the memory of a machinist might be, it would be convenient for him to have a book of primary principles and processes to which he could refer with confidence.

JUST PUBLISHED.

ıtions, 6*s*.

SAMPLE OF OUR SECTIONAL RULED PAPER.

TRY IT !

and if you [illegible]d it send 25cts and we will mail you either

a Handy Sketching Pad, 10 in. by 8 in. ; or

a Han[illegible] [illegible]etching Book, 8 in. by 5 in., stiff cover

12 copies $2.50.

SPON & CHAMBERLAIN, 12 CORTLANDT ST., N.Y.

BOOK;

ATEURS.

ı, Brass, Bronze,
tmetal Working
nery, embracing
ıs of Tools and
and hinges, and
rough furniture,
Cabinet-Making
tery — Painting,
ds, Floors, and
ınds—Polishing
:al movements,
ırning in Wood
ork, Terracotta
elt, Zinc, &c.—
-Plastering and
nging, ordinary

and electric Systems — Lighting — Warming — Ventilating — Roads, Pavements, and Bridges — Hedges, Ditches, and Drains — Water Supply and Sanitation—Hints on House Construction suited to new countries.

E. & F. N. SPON, 125, Strand, London.
New York : 12, Cortlandt Street.

MECHANICAL MANIPULATION.

THE

A TREATISE (
FOR TH

Comprising the
and Manufact
and Grindi
how to v
va

By (

**96 4to plates,
letterpress, s**

Of the six chap
which the fundan
every class are sta
fibres of each artic
hammer operatio
shaping the comp
Engineers' tools
be used during a
thinking that the
he is supposed to
5, and 6. In the
are the elements
this chapter are th
The next chapter,
to render compre
the machine-shapi

In many cases hand-shaping is indispensable, such as sudden breakage, operations abroad, and on board ship, also for constructors having a limited number of machines. Turning and screw-cutting occupy the last chapter. In this, the operations for lining, centering, turning, and screw-forming are detailed and their principles elucidated.

The Mechanician is the result of the author's experience in engine making during twenty years; and he has concluded that, however retentive the memory of a machinist might be, it would be convenient for him to have a book of primary principles and processes to which he could refer with confidence.

JUST PUBLISHED.

In demy 8vo, cloth, 600 pages, and 1420 Illustrations, 6*s.*

SPONS'
ECHANICS' OWN BOOK;

A MANUAL FOR HANDICRAFTSMEN AND AMATEURS.

CONTENTS.

Mechanical Drawing—Casting and Founding in Iron, Brass, Bronze, nd other Alloys—Forging and Finishing Iron—Sheetmetal Working —Soldering, Brazing, and Burning—Carpentry and Joinery, embracing lescriptions of some 400 Woods, over 200 Illustrations of Tools and heir uses, Explanations (with Diagrams) of 116 joints and hinges, and Details of Construction of Workshop appliances, rough furniture, Garden and Yard Erections, and House Building—Cabinet-Making and Veneering — Carving and Fretcutting — Upholstery — Painting, Graining, and Marbling — Staining Furniture, Woods, Floors, and Fittings—Gilding, dead and bright, on various grounds—Polishing Marble, Metals, and Wood—Varnishing—Mechanical movements, illustrating contrivances for transmitting motion—Turning in Wood and Metals—Masonry, embracing Stonework, Brickwork, Terracotta and Concrete—Roofing with Thatch, Tiles, Slates, Felt, Zinc, &c.— Glazing with and without putty, and lead glazing—Plastering and Whitewashing—Paper-hanging—Gas-fitting—Bell-hanging, ordinary and electric Systems — Lighting — Warming — Ventilating — Roads, Pavements, and Bridges — Hedges, Ditches, and Drains — Water Supply and Sanitation—Hints on House Construction suited to new countries.

E. & F. N. SPON, 125, Strand, London.
New York: 12, Cortlandt Street.

SPONS' DICTIONARY OF ENGINEERING,

CIVIL, MECHANICAL, MILITARY, & NAVAL,

WITH

Technical Terms in French, German, Italian, and Spanish.

In 97 numbers, Super-royal 8vo, containing 3132 *printed pages* and 7414 *engravings.* Any number can be had separate: Nos. 1 to 95 1*s.* each, post free; Nos. 96, 97, 2*s.*, post free. *See also page* 112.

COMPLETE LIST OF ALL THE SUBJECTS:

In super-royal 8vo, 1168 pp., *with* 2400 *illustrations*, in 3 Divisions, cloth, price 13*s*. 6*d* each ; or 1 vol., cloth, 2*l*. ; or half-morocco, 2*l*. 8*s*.

A SUPPLEMENT

TO

SPONS' DICTIONARY OF ENGINEERING.

EDITED BY ERNEST SPON, MEMB. SOC. ENGINEERS.

Abacus, Counters, Speed Indicators, and Slide Rule.
Agricultural Implements and Machinery.
Air Compressors.
Animal Charcoal Machinery.
Antimony.
Axles and Axle-boxes.
Barn Machinery.
Belts and Belting.
Blasting. Boilers.
Brakes.
Brick Machinery.
Bridges.
Cages for Mines.
Calculus, Differential and Integral.
Canals.
Carpentry.
Cast Iron.
Cement, Concrete, Limes, and Mortar.
Chimney Shafts.
Coal Cleansing and Washing.
Coal Mining.
Coal Cutting Machines.
Coke Ovens. Copper.
Docks. Drainage.
Dredging Machinery.
Dynamo - Electric and Magneto-Electric Machines.
Dynamometers.
Electrical Engineering, Telegraphy, Electric Lighting and its practicaldetails,Telephones
Engines, Varieties of.
Explosives. Fans.
Founding, Moulding and the practical work of the Foundry.
Gas, Manufacture of.
Hammers, Steam and other Power.
Heat. Horse Power.
Hydraulics.
Hydro-geology.
Indicators. Iron.
Lifts, Hoists, and Elevators.
Lighthouses, Buoys, and Beacons.
Machine Tools.
Materials of Construction.
Meters.
Ores, Machinery and Processes employed to Dress.
Piers.
Pile Driving.
Pneumatic Transmission.
Pumps.
Pyrometers.
Road Locomotives.
Rock Drills.
Rolling Stock.
Sanitary Engineering.
Shafting.
Steel.
Steam Navvy.
Stone Machinery.
Tramways.
Well Sinking.